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COMPARISON OF MANUAL AND AUTOMATIC TORQUE DEVICES IN IMPLANT SUPPORTED PROSTHESES

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MASTER'S THESIS

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DECLARATION

I thus certify that this thesis is my original work and that, to the best of my knowledge and belief, it contains no material previously published or authored by another person, nor material that has been accepted for the award of any other degree, save where proper recognition has been provided in the text.

10.07.2022
Mert YİĞİT

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LIST OF SYMBOLS and ABBREVIATIONS

N-cm	Newton-centimetre
MIC	Minimum inhibitory concentration
IT	Insertion torque
ISQ	Implant Stability Quotient
LCD	Liquid Crystal Display

ABSTRACT

Yiğit M. Comparison of Manual and Automatic Torque Devices in Implant-Supported Prostheses. T.C. Yeditepe University Institute of Health Sciences Prosthetic Dental Treatment Department, Istanbul 2021.

Implant treatment is a functional and aesthetic solution for tooth loss. Implant stability is one of the most important criteria for the long-term success of osseointegrated implants. There are two types of stabilization when establishing an implant-bone connection; primary and secondary. In long-term control studies of implant success, it has been determined that many complications may occur following the prosthetic phase. These complications; fractures in implant components, fractures in the superstructure, abutment loosening, marginal bone loss, and osteointegration impairment. The most common technical complication was abutment screw loosening. Based on the previous knowledge, this study aimed to compare manual and automatic torque devices in implant-supported prostheses in terms of torque success. A total of 40 implants, abutments, and screws were used by dividing into two main groups according to the brands (Alpha Dent n=20; Mode n=20). After that, ten implants, abutments, and screws of the same brand in the subgroups were at 15 N-cm, 25 N-cm, and 35 N-cm by tightened with a manual torque wrench (ratchet) or automatic screwdriver. Finally, the screws were loosened with a torque measuring device, and the unscrewing torque values were noted. In all three torque values, higher torque values were obtained in the abutments of the alpha dent implant than mode implant abutments. There was no significant difference between the brands in the three torque values in the automatic torque device. There was a significant difference between the two brands at 15 N-cm in manual torque devices. In all three torque values, the torque value obtained with the Alpha Dent implant's own ratchet was found to be higher than the torque value obtained from the automatic screwdriver, and the difference in the torque value of 15 N-cm was found to be significant. The torque value of the Mode implant at the torque value of 25 N-cm and 35 N-cm was found to be higher than the torque value obtained from the automatic screwdriver, the torque value obtained from the automatic screwdriver at the value of 15 N-cm was higher, and no significant difference was found. Regardless of the implant brand, when the torque values obtained from the implant brands' own ratchet and the torque values obtained from the automatic screwdriver were examined together, the values obtained from the screwdriver in each of the three different torque values were higher than the screwdriver, and the significant difference was found only in the torque value of 15 N-cm.

Keywords: Dental implants, Implant stability, Torque

ÖZET

Yiğit M. İmplant Destekli Protezlerde Manuel ve Otomatik Tork Cihazlarının Karşılaştırılması. T.C. Yeditepe Üniversitesi Sağlık Bilimleri Enstitüsü Protetik Diş Tedavisi Anabilim Dalı, İstanbul 2021.

İmplant tedavisi diş kayıplarına fonksiyonel ve estetik bir çözümdür. İmplant stabilitesi, osseointegre implantların uzun vadeli başarısı için en önemli kriterlerden biridir. İmplant-kemik bağlantısı kurarken birincil ve ikincil olmak üzere iki tip stabilizasyon kullanılır. İmplant başarısının uzun süreli kontrol çalışmalarında protetik fazı takiben birçok komplikasyonun oluşabileceği belirlenmiştir. Bu komplikasyonlar; implant bileşenlerinde kırıklar, üst yapıda kırıklar, abutment gevşemesi, marjinal kemik kaybı ve osteointegrasyon bozukluğu. En sık görülen teknik komplikasyon abutment vidasının gevşemesiydi. Bu çalışmada, önceki bilgilerden hareketle implant destekli protezlerde manuel ve otomatik tork cihazlarının tork başarısı açısından karşılaştırılması amaçlanmıştır.. Bu çalışmada markalarına göre (Alpha Dent n=20; Mode n=20) iki ana gruba ayrılarak toplam 40 adet implant, abutment ve vida kullanılmıştır. Daha sonra manuel veya otomatik tork anahtarı ile alt gruplarda aynı marka on adet implant, abutment ve vida sırasıyla 15 N-cm, 25 N-cm ve 35 N-cm sıkıldı. Son olarak tork ölçüm cihazı ile vidalar gevşetildi ve söküm değerleri not edildi. Her üç söküm değerinde de alpha dent implantın abutmentlarında mode abutmentlardan daha yüksek söküm değeri elde edilmiştir. Otamatik torklamada üç söküm değerinde de markalar arası anlamlı fark bulunamamıştır. Manuel torklamada 15 N-cm de iki marka arası anlamlı farklılık saptanmıştır. Her üç söküm değerinde de alpha dent implantın kendi raşeti ile elde edilen söküm değeri, otomatik screwdriverdan elde edilen söküm değerinden daha yüksek bulunmuş olup, 15 N-cm söküm değerindeki fark anlamlı bulunmuştur. 25 N-cm ve 35 N-cm söküm değerinde mode implantın kendi raşeti ile elde edilen tork değeri, otomatik screwdriverdan elde edilen söküm değerinden daha yüksek bulunmuş olup, 15 N-cm değerinde otomatik screwdriverdan elde edilen söküm değeri daha yüksek olup, anlamlı farklılık bulunamamıştır. İmplant markasına bakmaksızın implant markalarının kendi raşetinden elde edilen söküm değerleri ile otomatik screwdriverdan elde edilen söküm değeri karışık olarak incelendiğinde de üç farklı tork değerinin her birinde raşetlerden elde edilen değer screwdriverdan yüksek olup, anlamlı fark sadece 15 N-cm söküm değerinde bulunmuştur.

Anahtar Kelimeler: Dental implantlar, İmplant stabilitesi, Tork

1. INTRODUCTION AND PURPOSE

According to the dictionary of prosthetic terms, dental implants are fixed or mobile prosthetic devices made of alloplastic material to provide retention and stability for prostheses, implanted below the periosteal layer and above or within the bone (1).

Developing technology has produced much more functional and aesthetic solutions for tooth loss than before. In tooth loss, adjacent teeth were cut, and bridges were made until recently. This solution was far from being aesthetically pleasing, but more importantly, it was a treatment method that negatively affected the health of adjacent teeth in the long term. For more tooth loss, patients had to use removable (snap-on dentures or overdentures) prostheses. Thanks to implant treatment, tooth deficiencies are treated just like a new tooth erupts into the mouth. The implant can be applied to almost anyone without serious health problems (2).

Implants are metals similar to a tooth root placed in the jawbone to replace missing teeth and teeth with prostheses. Often implants are made of pure titanium or alloys with other metals such as aluminium (3). It has different forms, such as a screw or flat cylinder (4,5).

For the long-term success of osseointegrated implants, an essential criterion sought is that the implant is stable in the bone. There are two types of stabilization when establishing an implant-bone connection; primary and secondary (6). Initial primary implant stability is created by mechanical macro retention in the bone wall of the implant bed. The bone is reformed during healing. Biological connection occurs with tissue on the implant surface and newly formed bone; thus, primary stability changes with secondary stability. Changes in the healing and maturation period of the tissue formed in the bone-implant connection determine the degree of secondary implant stability (7,8). Rehabilitation of tooth losses with implant-supported prostheses, lost dental function and any changes of its anatomy to neighbouring teeth or conservative treatment without injury give the opportunity. Today, implant treatment is considered successful not only in osteointegration and survival of the implant but also in the long-term stability of the upper prosthesis, depending on its aesthetic and functional results and its ability to be cleaned (9).

Dental implants' frequent mechanical problems are loosening the screw in the screw connection between the implant-abutment and screw breakage. Chronic periimplantitis is the leading biological problem. The success of the implant is determined by the changes in the bone within the physiological limits, maintaining osteointegration. The success of the prosthetic structure is measured by maintaining the integrity and continuity of the parts. In intraoral implants, screw loosening depends on the geometry of the mechanical connection at the implant-abutment interface and bearing power, the preloading force of the abutment screw, micro-mobility, and the dynamic environment of the implant. The main cause of biological complications is not being cleaned and retention areas in implant design (5).

Among the criteria indicative of implant failure, important ones are the formation of mobility in the implant and the appearance of alveolar bone resorption around the implant. With clinically applied tests, failure with predictable and stability evaluation of osseointegration status can be determined (6).

To prevent implant failure, metal and metal alloys used in implants constitute a crucial place. Titanium has good biocompatibility and fine corrosion resistance, and mechanical features that it is widely used for various medical applications, as well as dental implants. Thus, titanium and titanium alloys are considered the gold standard for endosseous dental implants. With advancing technology and the growing pharmaceutical and medical device market, various types of titanium-based dental implants are now commercially available from many manufacturers.

Primary stability may be established after implant implantation by measuring insertion torque (IT) values or resonance frequency analysis (Implant Stability Quotient-ISQ). Many clinical and implant-related characteristics can have an impact on IT and ISQ (10,11).

The five most regularly utilized systems in the United States were addressed in the vocabulary (12, 13, 14, 15, and 16), with no actual production as a pattern; prosthetic screws, prosthesis coping, analogue, transfer coping, abutment.

The prosthodontic classification proposed by Misch (17) is used for communication among implant team members. Accordingly, the final prosthesis was described depending on whether the quantity of hard and soft tissues replaced was removable or fixed. The first three classes are fixed types defining the appearance of the prosthesis. The last two classes are removable types defining the amount of the implant support, not the prosthesis' appearance

McGlumphy et al. (18) described a screw junction as two elements kept together by a screw, including an abutment and implant. Torque is used to fasten a screw, and the torque imparted generates a force within the screw known as the preload. Tightening a screw causes it to elongate, causing tension. The screw's elastic recovery pushes the two sections together, providing a clamping force (19). The screw's preload caused by extension and elastic recovery is equivalent to the clamping force in quantity (20). A joint-separating force opposes the clamping force, attempting to split the screw connection. Screw loosening happens when the joint-separating forces operating on the screw connection are higher than the clamping forces keeping the screw component together (20). Too many pressures create sliding between the screw and bore threads, leading to reduced preload (21). It is not required to avoid separation forces; instead, they must be minimized (20). Screw loosening can be avoided by decreasing separation forces and increasing clamping forces.

Screws of various shapes and materials are used to link dental prostheses to implants and abutments. It was noticed that utilizing the suggested design of screw and type of metal for each abutment and implant is the best method. (22-24) Tightening screws to the proper torque value is essential for this operation. Evidence shows that not enough torquing an implant screw can result in screw loosening, breakage, failure (20), and, eventually, prosthesis failure. Screw distortion, screw loosening, and breakage can result from torquing more than needed. (27) On implant screws and abutments, hand-held screwdrivers have been demonstrated to give unpredictable torque levels (25). When experienced clinicians utilized hand-held drivers to create 32 N-cm of torque, one research showed values ranging from 8.2 to 36.2 N-cm. (28) Dellinges and Tebrock tested the torque delivered to a hex wrench by dental students; the average torque generated was 11.5 N-cm and depended on the operator's level of expertise. (29)

In keeping with the technological developments in dentistry in recent times, manufacturers have developed new electronic torque drives. An electronic torque drive can provide equal torque without being affected by the usage environment. The torque value requested by the practitioner is applied in digital format to the abutment screw with the electronic torque driver, and the torque value may be monitored on the LCD screen. (30).

Based on the previous knowledge, this study aimed to compare manual and automatic torque devices in implant-supported prostheses in terms of torque success.

2. GENERAL INFORMATION

2.1. Bone

Except for the sesamoids, the mature human skeleton consists of 213 bones (31). Bone is a connective tissue that is metabolically active. It offers structural support, protection of critical structures, movement facilitation by supplying muscle levers, acid-base homeostasis management, growth factor and mineral reservoirs, and a location for haematopoiesis (32). Bones can be characterized in various ways, including location, form, consistency, and size. (31, 33, 34).

2.1.1. Types of Bone

Tubular bones consist of upper and lower extremities' long bones, metatarsals, metacarpals, phalanges, and clavicles. Long bones are made up of 3 different regions: diaphysis, metaphysis, and epiphysis. The diaphysis mainly forms the shaft, consisting of dense cortical bone, and the metaphysis is the enlarged region at both ends. On the other hand, the epiphyses include the part containing the articular surface immediately adjacent to the metaphysis, in which a thin cortical cover wraps the cancellous bone. (31, 33).

The flat bones mainly form- the cranial and facial skeleton, scapula, sternum, and ribs. They are predominantly cancellous bone covered with thin cortical shells and do not include diaphysis, metaphysis, or epiphysis (31).

2.1.2. Structure of Bone

The overall structure of the bone is composed of a core medullary region encased with bony tissue and periosteum (Figure-1) (33). Cortical and cancellous bones are the two main structural types of bone. Even hough both share the same matrix constitution, their density, three-dimensional architecture, and metabolic activity are all different from each other (31, 33, 34).

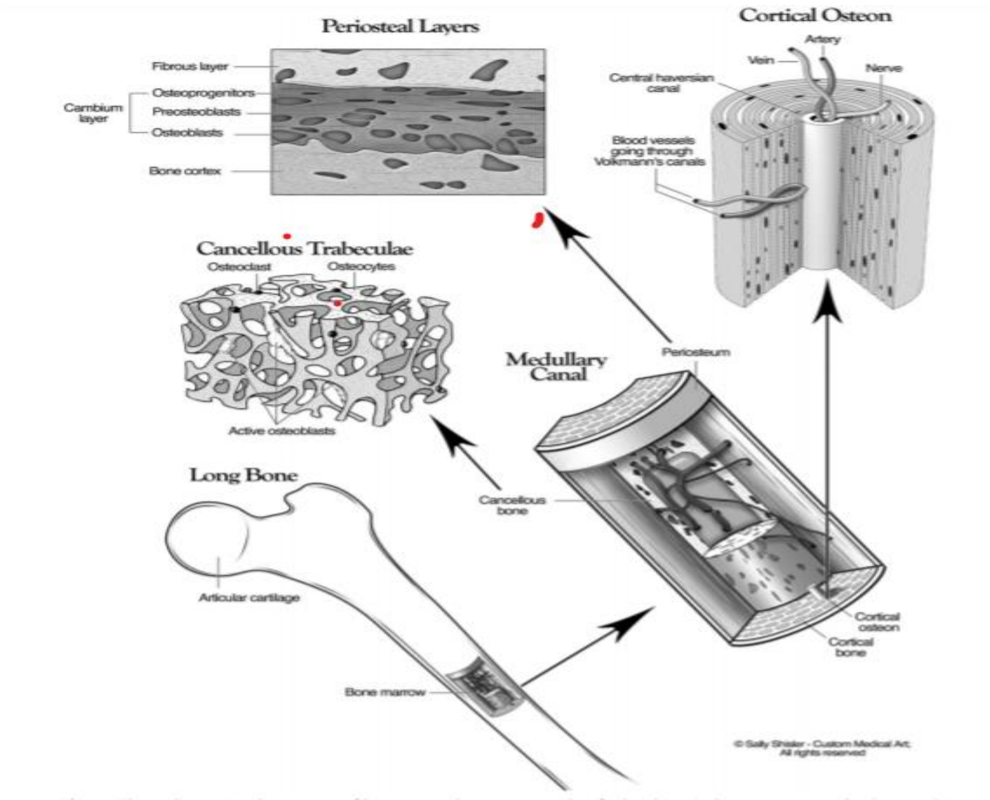

Figure 1. Bone’s three-dimensional structure.

The mature adult skeleton weight of 80 per cent is formed by cortical bone. Cortical bone offers compressive strength as well as maximal resistance to torsion and bending due to its 5 to 10% porosity structure. On the other hand, Cancellous bone has a porosity of 50 to 90 per cent. Despite accounting for just 20% of the adult human skeleton, it has a far higher surface area per unit volume (31, 33, 35). Cancellous bone's principal property is the absorption of loads and allowance of deformation (33). Additionally, it has a high metabolic activity and remodelling rate. Due to the layer of primary bone cells on the surface adjacent to the circulation growth factors and cytokines, cancellous bone can give a prompt response to mechanical impulse (33, 34).

There are two histologic components of bone: primary (woven) and secondary (lamellar) bone (33). The embryonic skeleton is formed by primary bone, which is then resorbed during development. Primary bone temporarily occurs in growth plates and during the early phases of fracture healing. It is weak and flexible due to its non-uniform mineral and collagen fibril pattern. Secondary bone is highly structured, with densely packed collagen fibrils in sheets, consistent osteocyte distribution, and bone matrix dispersion. It permanently replaces the primary bone during the growth process and the later phases of fracture healing. Its highly organized structure provides rigidity and strength (33, 18).

Secondary bone has four main structural types: osteons, circumferential, trabecular, and interstitial (33, 34, 37). Osteons are the most significant component of the lamellar bone, comprising the cortical bone's basic structural unit and the diaphyseal shaft (Figure-1).

They are formed by longitudinal cylinders running parallel to the bone's long axis. Osteons are made up of concentric lamellae that surround central Haversian canals and are covered by endosteal cells. Furthermore, osteons include blood and lymphatic vessels and nerves (34, 37). Osteocyte canaliculi rise from the central canal radially, connecting the central canal to osteocytes, and facilitating the transport of nutrients to the matrix. Accordingly, this longitudinal axis structural model explains its higher resistance to fractures with a parallel mechanical blow than perpendicular loads (31, 36, 37).

Osteons comprise four to twenty concentric lamellar layers of bone with a definite border between them known as the cement line (34, 37). Cement lines are thin layers of the organic matrix that define the points at which bone resorption ends and new bone production begins. Cement lines serve as wrappings around osteons, isolating them from nearby osteons. As a result, fractures usually occur along the cement lines instead of crossing osteons. This result is beneficial since it reduces fatigue fractures from rapidly expanding horizontally across the bone, allowing time for healing before a full fracture develops (37).

Cancellous bone involves lamellar bone; however, its formation is different from osteon. Cancellous lamellae are organized in semi-circular patterns termed "packets," which produce the visible bone trabeculae in three dimensions (Figure-1) (37). The trabecular structure provides an enormous surface area to cancellous bone, which is an essential trait that influences the pace of bone graft integration (37). Cancellous trabeculae are far more cellular than cortical osteons, with more vascularity and metabolic activity. Haversian canals do not exist in cancellous trabeculae, and they lack central arteries in favour of sinusoids, which facilitate interaction between bone structural units and marrow (37).

The periosteum is a double stratified formation consisting of a thick, hypocellular external layer that extends into joint capsules and joins neighbouring bones and an inner layer, called the cambium, which includes osteoprogenitor cells a vascular plexus (Figure-1) (33). The periosteum surrounds the outside of the bone and is connected to the external cortex by dense collagenous fibres known as "Sharpey's fibres" (31). The periosteum serves as a connection point for various ligaments and tendons and provides blood flow to the bony cortex's external third (31).

Periosteal cells may also remineralize and produce bone after stimulation, and they play an essential role in the early durability and callus development throughout acute healing of the fracture (33). Volkmann's canals are oblique channels inside the bone matrix that connect periosteal cells to the endosteum and marrow cavity. The periosteum, similar to other forms of connective tissue, depends on age (33). The thick cellular cambium overlay nearly vanished during skeletal maturation and lose most of its osteogenic ability (33).

The endosteum is a membranous tissue that limits the Volkmann's canals and surrounds the inner surfaces of bone. The endosteum is entirely cellular, with vessels and osteoprogenitor cells communicating directly with the marrow area (31).

The bone's primary blood supply is a complicated interosseous canals and sinusoids system, which ensures no cell is more than 300 nm from a vessel (33, 34). Despite blood circulation to bone depends on region, generally, the skeletal system receives 10 to 20% of cardiac output at rest, an amount comparable to that obtained by the kidneys (34, 38).

Tubular bones contain a double supply of blood. The primary supply is through nutritional diaphyseal vessels, which frequently penetrate the diaphysis's middle third (31, 34, 39). After entering the diaphysis, these vessels reach the medullary canal and divide into ascendent and descendent branches. The inner two-thirds of the cortex and the medullary canal are nourished by the diaphyseal nutritional veins (33, 34, 39).

There are countless tiny metaphyseal and epiphyseal capillaries that emerge from the blood vessels that supply the neighbouring joint and unite with the diaphyseal vessels (33). The physeal cartilaginous plates divide the metaphyseal and epiphyseal veins in developing bones. As a result, the epiphyseal and physeal blood supply is less intense, which elucidates why fractures in this zone cause growth retardation (33).

A periosteal vascular plexus, which supplies the external part of the cortex, is another crucial element of the long bones' blood supply. Volkmann's canals connect periosteal veins to diaphyseal vessels. This plexus, in particular, is dependent on links with surrounding skeletal muscle.

The venous drainage accompanies the nutritional arteries and the periosteal venous plexuses (34, 39). Flat bones have a double circulation system that includes nutrition arteries as well as perforating periosteal vascular plexuses. The primary vascular supply of the mandibular bone is often derived from branches of the maxillary artery. The calvarium is accessed through perforating branches of the middle meningeal artery, which runs parallel to the inner layer (40). Perforators from the overlaying vasculatures supply the periosteal plexus, including the occipital, superficial temporal, supraorbital, and supratrochlear arteries in the calvarium (40). Although the periosteum's vascular connections are weakly established, it was demonstrated that vascularized calvarial grafts might be built using this approach if the galea and vessels stay attached to the calvarial graft (40). The nutritional arterial venae comitantes, the venous plexus of the periosteum, and the diploic veins draining into the dural venous sinuses parallel the vascular supply of flat bones.

Plastic surgeons, particularly those who manage complicated fractures or conduct head and neck reconstruction, should be familiar with bone blood flow. In comminuted mandible fractures, for example, the survival of the bone pieces is nearly dependent on the participation of the periosteum. In these circumstances, open reduction and fixation with accompanying periosteal stripping may pose risk for necrosis and bone resorption, which is why closed reduction is indicated in those types of lesions.

2.1.3. Bone Cells

Bone cells account for around 10% of total volume bony tissue. They are derived from osteoprogenitor and hematopoietic cells (31, 33). Osteoprogenitor cells, which differentiate into osteoblasts, are found in the bone canals, periosteum, endosteum, and bone marrow. Vascular pericytes may potentially be a source of osteoprogenitor cells. Undifferentiated osteoprogenitor cells wait for cues to move to a place, multiply, and develop into osteoblasts. Osteoprogenitor cells are known as bone's "stem cells".

Osteoblasts cover the borders of bone and are densely packed together. It is thought that the bone-forming cells create and produce an organic bone matrix (31). The release of alkaline phosphatase indicates osteoblast activation. When activated, they either stay quiescent osteoblasts, become osteocytes, or revert to the osteoprogenitor cell line (31, 31). Morphogenic proteins of bones and various transforming growth factor family members are critical osteoblast development and activation mediators (39).

Osteocytes constitute 90% of all bone cells (31). Osteoblasts that have wrapped themselves with organic matrix to dwell within vacuoles, named lacunae. They generate cytoplasmic projections that penetrate the bone and touch cell processes of neighbouring osteocytes, enabling direct communication once covered by a matrix. Osteocytes are in charge of the the bone matrix preservation as well as calcium homeostasis. They can also be selectively stimulated for bone resorption by parathyroid hormone (31).

Osteoclasts are giant cells living in shallow recess on bone surfaces known as Howship lacunae and have multiple nuclei (31). They can also dwell in deep resorption voids known as cutting cones during the remodelling and healing phases. Osteoclasts are bone-resorptive cells that connect to the bone matrix via a brush edge and acidify it, permitting matrix phagocytosis. Osteoclasts can resorb only mineralized bone (31, 33).

Many recognized agents and cytokines, such as the receptor activator of NF-ligand, macrophage colony-stimulating factor, osteoprotegerin, interleukin-1 and 6, 1,25-dihydroxy vitamin D, calcitonin, and parathyroid hormone, influence osteoclast development and activity. (31, 41, 42).

2.1.4. Bone Composition

The bone matrix accounts for 90 per cent of total bone volume. It is made up of four primary constituents: inorganic or mineral matrix (65%), organic matrix (20%), lipids, and water (15%). (31).

The mineral matrix is responsible for 99 per cent of the body's calcium storage, 85 per cent of phosphorous storage, and 40 to 60 per cent of magnesium and salt storage (33). Most of the bone strength, rigidity, and resistance to compressive stresses is provided by the inorganic matrix, which is mainly composed of hydroxyapatite (33). The loss of the inorganic matrix causes the bone to be fragile, pliable, and spongy, as in osteomalacia caused by a lack of vitamin D (43).

The organic matrix, which is produced by osteoblasts, is mostly composed of type I collagen (90%) and includes glycoproteins, proteoglycans, and growth factors (33). Bone morphogenic proteins, other transforming growth factors, interleukin-1 and 6, osteonectin, osteocalcin, and bone sialoprotein are examples of these growth factors

(31, 44). All of these variables are important in bone mineralization, osteogenesis, and remodelling (44). The organic matrix provides bone with its shape and strength to tensile stresses. Osteogenesis imperfecta, which results in stiff and fragile bones, is a well-known organic matrix abnormality (45).

The bone morphogenic proteins, found by Urist in 1965, are one of the essential elements of the bone matrix (46). There are 20 different bone morphogenic proteins, which are components of the transforming growth factor-superfamily. Embryologically, they are crucial mediators in the formation of the nerves, heart, and neural crest. They contain osteoinductive characteristics that are important in postnatal bone growth and repair. Presently, there are two licensed bone morphogenic proteins in clinical usage, and both have demonstrated tremendous promise in aiding bone repair and development (46).

Mineralization is the process by which soluble calcium and phosphate are converted into solid, crystalline calcium phosphate inside the organic matrix. Even though not completely understood, mineralization is considered to be coordinated by osteoblasts and takes place 10 to 15 days after the organic matrix is secreted (31, 47).

2.1.5. Bone Formation

Even though the neural crest has an important role in the foetal development of the inner ear and a part of the craniofacial skeleton, bone is mainly formed through mesodermal descent. Fetal bone formation occurs in one of two ways: endochondral ossification or intramembranous ossification. It is worth mentioning that the two forms of embryonic bone development correspond to the two types of adult bone repair (47, 48).

Bone formation via a cartilaginous precursor is a defining feature of endochondral ossification (48, 49, 50). It is the most crucial phase in the development of long bones, and it is also required for long-bone longitudinal formation at the physeal zone and the natural bone repairment process. The activation of chondrocytes promotes endochondral ossification into a four-zoned hyaline cartilage structure (49, 50).

The resting zone comprises regular chondrocytes and is the farthest away from the bone growth section. As chondrocytes increase in number (proliferative zone), they enlarge (zone-3) and secrete alkaline phosphatase, leading to chondrocyte apoptosis and the production of angiogenic factors such as vascular endothelial growth factor. The calcification zone (zone of dead chondrocytes) forms an arid matrix that favours capillary angiogenesis and the accumulation of osteoprogenitor cells. The osteoprogenitor cells eventually develop into osteoblasts, which are responsible for bone formation (49, 50).

In contrast to endochondral ossification, intramembranous ossification is distinguished by spontaneous bone production without a cartilaginous mediator (50). This happens during the generation of flat bones, early bone repair, and distraction osteogenesis (48, 50, 51, 52).

Intramembranous ossification is the spontaneous formation of an ossification unit inside the extracellular matrix caused by the transformation of mesenchymal stem cells into osteoprogenitor cells, which then increase and convert into osteoblasts (50).

Long bones are formed longitudinally by endochondral ossification at the physeal plate (Table-1) (53). On the other hand, radial bone formation happens through a process known as appositional bone growth. Appositional bone formation is the production of new bone at the periosteal level, followed by endosteal old bone resorption. This procedure is carried out by osteoprogenitor cells in the cambium region (39 54).

Table 1. The differences between endochondral and intramembranous ossification.

	Endochondral	**Intramembranous**
Process	Formation through a cartilaginous intermediate	Direct bone formation
Location	Embryogenesis of long bones	Embryogenesis of flat bones
	Longitudinal bone growth	Fracture healing
	Fracture healing	Predominant process during the distraction of osteogenesis

The phase of appositional bone formation is principally responsible for the development of the facial bones. Furthermore, both endochondral and intramembranous ossification has a role in increasing the craniofacial skeleton's size and shape during maturation (55). The skull's modelling is hypothesized to be regulated by mechanic transduction messages from brain development (55).

Wolff's law, which was introduced in 1892, claims that bones alter form to meet pressures. Consequently, bone undergoes resorption in the absence of stress and is strengthened where stress pressure is administered. A good example is the absence of regular masticatory forces' resorption of an edentulous jaw in the absence of regular masticatory forces. Local mechanical pressures can have a significant impact on bone transplants.

The mechanical requirements of the graft can cause changes in bone thickness, density, geometry, and trabecular alignment (56). Thus, while modelling plays an essential purpose in optimizing bone structural strength, it may also have negative consequences; bone grafts that are exceptionally sheltered from mechanical loads can lead to over-resorption of bone, and after then weakening, and fracture (56).

2.2. Dental Implants

2.2.1. Dental Implant History and Development

Attempts to solve the problem of tooth loss, which eventually led to the discovery of a method of replacing lost teeth, trace back as far as human history. Several substances, numerous geometric shapes, surgical and prosthetic procedures have been tested from ancient times to the contemporary age, till today's modern dental implants are produced. In terms of historical implantology, few archaeological accounts show the attempts of various prosthetic devices employed as natural and practical solutions. The archaeological findings indicate that many ancient communities employed transplantation processes and technologies. Furthermore, primitively manufactured pieces like wood, carved stone, cast engraved seashells, bone, iron, and natural teeth extracted from different animals, and teeth traded by destitute people have been tested as implantation elements (57).

Archaeologists discovered a female's jawbone of Mayan provenance in 1931, with tooth-shaped bits of shell inserted into the cavities of missing teeth. Subsequently, in 1970, Professor Amadeo Bobbio, a Brazilian dentistry scholar, analysed that jawbone sample, and in the radiographic images, he saw bone development surrounding the implant-like objects (58). Teeth contributed by humans were substituted for lost teeth of wealthier individuals in the 18th century in return for payment; nevertheless, immune system responses prevented the adaption of foreign substances. Le Mayeur implanted 170 contributed teeth in 1785 and 1786, but none of them succeeded (59). Silver, gold, platinum, and several other metallic alloys were employed as implant composites in the nineteenth century, based on the mistaken belief that valuable metals would be easily tolerated by human tissue, resulting in exceedingly poor long-term results (59). These implants were put in alveolar holes instantly after extraction to provide adequate replacements. The rejection of these metallic elements mainly was owing to their lack of inertness. Venable et al.'s experimental work in 1937 revealed that metals that are not inert seem to ionize when they come into contact with biological fluids, causing the formation of metallic salts that cause considerable proliferation of some tissues while preventing osteogenesis (60). Implant failure is caused by the inhibition of bone development surrounding the implant.

Professor Bränemark, a Swedish orthopaedic surgeon, made a sort of coincidence in 1952 that resulted in recent advancements in dental implantology. He researched bone repair and regeneration in rabbits using a titanium chamber created and constructed at Cambridge University. Finally, he discovered a microscopical bone formation around the titanium surface, and he could not remove the chamber from the rabbit femur. Dr Bränemark examined this effect further through tests on animals and volunteers, all of which led to the discovery of titanium's biocompatible qualities. Titanium was first thought to be suitable for orthopaedic implants, including knee or hip; however, it was discovered that metal could also be used as anchors for implants and prosthetic crowns (61).

The first titanium prosthesis was placed in the mandible of a volunteer, Gösta Larsson, in 1965 to give a synthetic base for prosthetic teeth (58). Leonard Linkow also unveiled his blade-form titanium implants in 1967, which provided mechanical stability and efficiency for partial and complete dentures (61). Researchers conducted several experimental investigations between 1970 and 1980 to improve titanium dental implants' patterns and geometric forms, including the TPS, IMZ, and ITI Hollow-Cylinder Implants (62). Dr Bränemark carried on his research during this time, and in 1971 he developed titanium hollow screw implants. This material resulted in a higher rate of success, clinical accuracy, and a lower risk of problems than blade-form implants. Dr Bränemark released a paper in 1977 that included all of the data from his research. This research provides scientific information for the development of presently used implantation processes and implant systems (61). In 1978, he formed a business collaboration with Bofors AB, a Swedish defence corporation. Nobel Biocare, one of the world's major present dental implant makers, was created in 1981 based on the collaboration to target only dental implantology. The first recommendations for effective implant dentistry were established in 1982 at the Toronto Osseointegration in

Clinical Dentistry Conference (63). Screw-shaped dental implants have been the favoured technique of tooth replacement and a common dental treatment approach because o the excellent integration of hollow screw geometry into the bone and the high biocompatibility of titanium. Dental implants, sold under numerous trademarks, are now widely utilized worldwide, with a high success rate and a wide range of therapeutic choices. Ongoing researches primarily focus on enhancing aesthetics, shortening recovery time, and facilitating the usage of dental implants.

2.2.2. Dental Implant Indications and Contraindications

Indications:

Dental implants can effectively repair all types of partial and total edentulism. Implant-supported dentures are the technique of choice for repairing all forms of toothless gaps in the absence of any contraindications. Here are a few examples of when dental implants are highly recommended:

In case of the absence of a single tooth, an implant-supported crown preserves the nearby natural teeth by eliminating the requirement for preparation. If a standard dental bridge is used to fill the toothless gap, both neighbouring teeth must be prepped (Figure 2.). This procedure includes completely removing sections of the natural structure of the teeth, including pieces that may still be healthy and structurally good.

Figure 2. The single entity toothless gap with healthy adjacent teeth (left). The optimum treatment option is an implant-supported crown (right).

Kennedy class 1 is bilateral, and Kennedy class 2 is the unilateral absence of numerous teeth (molars and/or premolars) on the posterior side of the dental arch. Conventional dental bridges supported by natural teeth are challenging to create in these circumstances since the rear support tooth is lacking. In most cases, removing partial dentures necessitates the production of additional teeth (Figure 3.). Although more expensive, implant-supported prostheses are strongly recommended in these clinical conditions.

Figure 3. Partial edentulism with the back (posterior) teeth are missing (left)—implant-supported bridge (right).

In the case of a complete edentulism, the only proper option is a complete removable denture. Either fixed or removable implant-supported prosthesis improves chewing speaking clarity and stability (Figure 4.).

Figure 4. Complete edentulism (left). Full denture (middle). Implant-supported removable denture (right).

Patients who are unable to endure a detachable restoration (removable denture), as well as those with high cosmetic and functional expectations, are also candidates for dental implants.

Contraindications:

General contraindications:

Severe disorders that render anaesthesia and surgery constitute ***absolute contraindications***. In that case, overall placement is unsuitable.

- Recent infarcts, heart valve disorders, cardiomyopathy, and significant cardiac insufficiency,
- Bone illnesses (Paget's disease, osteomalacia, brittle bones syndrome, and so on), and active cancer,
- Immunosuppressive therapies and immunological illnesses, including AIDS, and candidates for an organ transplant,

- Various mental illnesses,
- Jawbones that have been heavily irradiated as a result of radiation treatment,
- The use of bisphosphonates to treat osteoporosis or certain cancers.

Relative contraindications include scenarios that should be handled individually. Dental implants can only be implanted with extreme caution after a series of preparatory therapies.

- Pregnancy,
- Uncontrolled diabetes mellitus,
- Coronary syndromes and angina pectoris,
- Significant tobacco consumption, substance abuse (drugs and alcohol),
- Several mental illnesses,
- Some auto-immune disorders,
- Age,

  Children should not have surgery until their jawbones have finished developing, generally before 17 or 18 years. However, senior age does not constitute an issue if the patient's overall health is good.

Local contraindications:

Some diseases or physiological differences, generally within the oral cavity, may impede the installation of dental implants for a short period of time. Most of the time, these issues may be addressed prior to the placement of implants in the mandible.

- There is not enough bone to sustain the implants, or the mandible is not strong enough as a result of such as chronic infections. For a favourable outcome, a dental implant should be covered by healthy osseous tissue (Figure 5.). There is insufficient bone to support the implants, or bone structure is inadequate (due to some chronic infections or other conditions). A dental implant must be surrounded by healthy bone tissue for a good prognosis (Figure 5.).

Figure 5. A dental implant should be supported by healthy osseous tissue (with red).

- The maxillary sinus and the inferior alveolar nerve (placed inside the jaw) have an irregular location that might impede dental implants (Figure 6.). In such circumstances, additional interventions should be undertaken prior to the implantation of dental implants to enhance the quantity of bone available to support the implants.

Figure 6. Lowering of the maxillary sinus.

- Inadequate oral hygiene,
- Many local disorders of the oral cavity or alveolar bone might potentially prohibit dental implant insertion until the circumstances are addressed,
- Bruxism,
- Rarely hypersensitivity or other allergic responses.

2.3. Dental Implant Types

2.3.1. Endosteal Implant

Endosteal implant systems were established before the emergence of transosseous implant systems to restore one or more teeth partiallly or total edentulous mandible. Endosteal or endosseous dental implants are inserted in the mandible or maxilla's alveolar or basal bone, transecting only one cortical plate. The apical section of the endosseous implant sometimes descends into the caudal cortical plate in the edentulous jaw. An implant inserted in this manner is still referred to as "endosseous."

Contrary to transosseous systems in which the retaining elements constitute a unit, these endosseous implants are considered individual elements. Individual implants can be adjusted or replaced if necessary. This is a significant benefit over transosseous systems, where difficulties necessitate a total modification of the overall design.

The endosseous dental implant comprises an anchoring element called the "endosseous dental implant body," which is preferably embedded in bone. The "endosseous dental implant abutment" is a retentive element. To explain the geometry of endosseous dental implants, definitions of the dental implant body that employ shape or geometric patterns as a conical cylinder, blade, or screw —can be used as descriptions (64). Brånemark and Schroeder's research teams were the first to investigate the direct interaction of bone and titanium endosseous implants (65, 66). This direct bone-to-implant link, known as osseointegration (67), resulted in several endosseous implant systems that may be employed in a clinical environment. It became evident that effective osseointegration required both the geometric structure and surface aspects of the implant and a thorough surgical procedure associated with an ideal condition of the implant site.

Geometric models were created for reasons, including the possibility of place and applicability (68, 69). This allows one to select an implant model that will provide the best circumstances for the patient's functional and cosmetic recovery. According to research on the surface characteristics of endosseous implants, these qualities not only play an essential role in the qualitative and quantitative features of the bone-implant junction, but they are also crucial in the time required to achieve a specific level of osseointegration (70, 71).

Endosseous implants have a precise clinical application in prosthetic dentistry. The earliest clinical data released by Swedish research organizations (67) revealed excellent clinical outcomes. After Zarb and his colleagues confirmed these findings, the use of titanium endosseous implants became generally recognized (72). Endosseous titanium implants are being used in both completely and partly edentulous individuals. Endosseous implants in the edentulous mandible have drastically revolutionized treatment paradigms; employing these implants allows the retention of both permanent and removable prostheses. This type of therapy enhances oral performance and results in high patient satisfaction (73, 74, 75, 76).

2.3.2. Eposteal Implant

Eposteal implants rely on the remaining bone of the jaw for primary bone support. The subperiosteal dental implant, also named as the subperiosteal frame, is the most often utilized eposteal implant device in this class (64). Intramucosal implants and ramus frames are two more uncommon techniques (77, 78). These initial kinds of implant therapy may be effective, but long-term research is inadequate. As a result, it is reasonable to believe that this treatment is either not long-term efficient, is utilized by a few physicians, or has been overtaken by new materials and procedures. In 1943, Dahl developed the subperiosteal frame (79).

Goldberg (80) and subsequently Linkow improved the method (81). Patients had to go through two surgical procedures. The surgeon raised a mucoperiosteal flap throughout the first procedure to expose the bony edentulous alveolar process and the adjacent basal mandibular bone. Following that, an imprint of the denture-bearing region was taken. During the second procedure, a custom-built frame consisting of a cobalt-chromium composite was implanted subperiosteally. Multiple transmucosal posts might be used to attach fixed or detachable prostheses. The idea of a subperiosteal frame was novel.

Transmucosal posts were created by inserting nonbiological substances into human tissues with open contact with the oral cavity. These posts might be used to secure fixed or detachable prostheses. Despite historical studies indicating ten-year survival rates ranging from 60% to 75% (82), participants displayed a variety of anatomical issues, such as epithelial ingrowth, implant avulsion, infection, and mental nerve paraesthesia (83, 84). These primary limitations caused the loss of the implant in over 60% of the participants studied during a 20-year follow-up study (85), even though cases of long-term (more than 25 years) success are documented (86, 87).

There is no precise data on the clinical performance of this system in terms of the amount of erosion of the inferior alveolar ridge, or comparative studies with other implant systems are present in the literature. Today, the approach of using a subperiosteal frame has almost been discarded since the effective recovery in a high subset of patients over a long period is poorer than that accomplished with alternative systems, including transosseous and endosseous systems (88). Furthermore, the transosseous and endosseous systems have lower adverse events than the subperiosteal frame. (76)

2.3.3. Transosteal Implant

Transosteal dental implants, also known as transosseous dental implants, are made up of a metal frame and transosteal posts or pins. The metal plate is kept in place by retaining pins or screws attached to the mandible's inferior aspect. This metal plate holds the transosteal posts in place, which pierce the whole depth of the mandible and protrude into the mouth in the inter-foraminal region (64). The "staple bone-implant" technique and the "transmandibular implant" method are the two types of transosseous dental implants utilized in humans (TMI) (76). The use of implants is not very common due to the difficult and extensive surgical technique. In case of failure, it is difficult to remove, and there is more damage to the surrounding tissues. (89)

2.4. Denture Supported by Implant

2.4.1. Prosthetic Components of Dental Implants

The general terminology for endosseous implant elements follows the same sequence as the technique of implantation and repairment (Figure 7). (90). The five most regularly utilized systems in the United States were addressed in the vocabulary (91, 92, 93, 94, 95), with no actual production as a pattern.

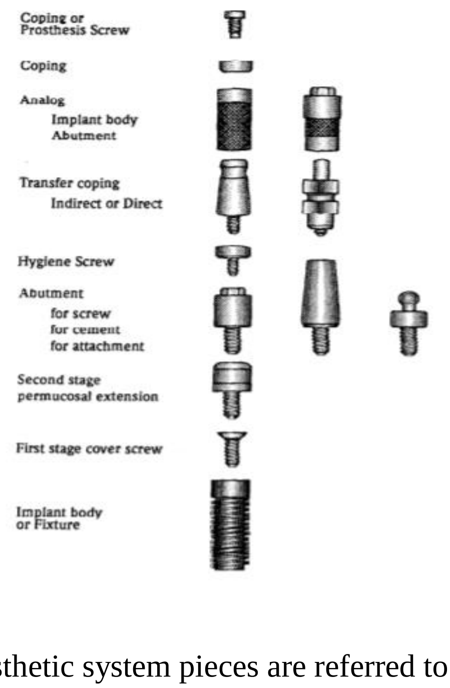

Figure 7. Implant prosthetic system pieces are referred to by broad terminology.

2.4.1.1. Prosthetic Screws

A dental implant mechanism with exterior hexagon or internal links can support two types of restorations: screw-retained implant crowns and cement-retained implant crowns. A coping screw or prosthesis screw secures a screw-retained prosthesis or superstructure to the implant body or abutment. The benefit of fastened prostheses is that they may be easily displaced without causing harm to the implant (96).

2.4.1.2. Prosthesis Coping

A coping is a tiny overlay typically intended to suit the implant abutment and link the abutment and the prosthesis or superstructure (64). A manufactured coping is often a metal coping that has been appropriately carved to suit the abutment. After that, the item is placed into the prosthesis or substructure. A castable coping is often a plastic design that has been burnt off and then put into the superstructure or prosthesis.

2.4.1.3. Analogue

An analogue is something analogous or similar to another. (64) There are two types of analogues: implant body analogue and abutment analogue.

The final print is made using an implant analogue to imitate the retaining section of the implant body or abutment. After securing the master imprint, the analogue is attached to the transfer coping. Before casting the imprint in stone, the indirect imprinting technique needs to adjust the transfer coping with an analogue into its proper impression zone (97). The analogue is attached to the transfer coping while remaining in the impression materials when using the direct impression technique.

2.4.1.4. Transfer Coping

A transfer coping is one that is used to place a die in an imprint (64). When defining the component utilized in the final imprint, most implant makers use the phrases transfer and/or coping. (91, 92, 93, 94, 95) As a result, a transfer coping is utilized to position an analogue of the implant body or abutment in an imprint.

There are two methods for transferring implant placements with transfer coping from the teeth to a master impression. (72) An **indirect transfer coping** is fastened into the abutment or implant body and is retained after the imprint is established and withdrawn from the mouth. (97) The indirect transfer coping is side by side or gently tapered to make removal of the pattern easier. It frequently features smooth edges or flat undercuts to aid in reorientation inside the imprint. A **direct transfer coping** comprises a hollowed transfer component, usually square, and a lengthy screw that secures it to the abutment or implant body. (97)

The imprint is formed through a panel at the tray's top, and once the impression material has been established, the transfer coping screw is unthreaded to extract the impression from the mouth. Because this transfer coping stays inside the impression after extraction, it does not depend on the elastic deformation of the filling material for correct transfer.

2.4.1.5. Abutment

The abutment is the part of the implant that maintains or holds a prosthesis or implant superstructure in place (64). A superstructure is a metal frame that matches the implant abutment and holds the prosthesis in place (64). An instance is a cast bar that links the implants and holds an overdenture in place using connections.

The mechanism for retaining the prosthesis or superstructure defines the three basic kinds of implant abutments. An **abutment for screw** retains the prosthesis or superstructure with the help of a screw. Cement is used in an **abutment for cement** to hold the prosthesis or superstructure in place. An **abutment for attachment** retains a detachable prosthesis using an attaching tool such as a magnet or O-ring.

For cement-retained prostheses, some producers label the abutments as "permanent," while for screw-retained prostheses, the abutments are classified as "removable" (92, 94, 95). This is incorrect because a permanent prosthesis is described as a restoration that is not detachable by the patient and may be cemented or screwed in place (64). Since these phrases define the abutments in the aspects of how the superstructure is attached to them, a metal bar screwed to the abutments may hold a prosthesis with attachments. The abutment, however, would still be categorized as an "abutment for the screw."

The abutments can be friction-locked, screwed, or cemented into the implant body. As a result, how the abutment is secured to the fixture or implant body is called friction-fit, screw-in, or cemented. When the terminology detailing how to retain the prosthesis and abutment is combined, words such as "cemented or screw-in abutment for attachment" arise.

Each of the three kinds of abutments is then subdivided into straight and angled abutments. The axial connection between the implant body and the abutment is described. Several cemented prostheses' straight abutments are tapered. However, the taper degree does not affect the abutment's connection to the implant body. A hygiene screw inserted over the abutment between restorative visits keeps debris and calculus away from reaching the internally threaded component of the abutment. An imprint is required to transfer the precise location and structure of the implant body or abutment to a master cast.

Abutment for screw:

An abutment for the screw is indicated in conditions in the posterior parts in which aesthetics is not the primary problem, and the implants must be placed deeply. The abutment for the screw is preferred when the upper part of the implant is more profound from the gingiva for 3 mm or more.

Advantages of the abutment for screw:

In cases with short crown lengths, the retention problem is solved using screw-retained abutments. The prosthesis can be removed very easily, and there is no need for cement.

Disadvantages of the abutment for screw:

Ideal occlusal morphology may not be preserved because the screw socket and aesthetics is difficult to achieve. After all, the screw can be seen in the occlusal. Passive adaptation is difficult to control. It is challenging to work with due to the short distance of the occlusal. It is challenging to provide load distribution, making it less resistant to screw loosening and breakage. Additionally, the screw may be lost. Porcelain fractures are more common in porcelain crowns with a narrow occlusal table (such as premolars) and in teeth where the screw is close to the occlusal edge. (98)

Abutment for cement:

This type of abutment is preferred in the upper anterior region, where the aesthetic appearance of teeth is prioritized. If the upper border of the implant is less than 2-3 mm deep from the gingiva, a cemented type abutment is preferred.

Advantages of the abutment for cement:

Technical complications are lower in cement-retained abutments than in screw-retained abutments. The occlusal surface of the prosthesis is similar to the natural tooth anatomy and is aesthetically advantageous. (99) Occlusal alignment is more easily achieved. The passive compliance of the infrastructure is easy. Abutment for cement allows the restoration of implants even they are not placed in the ideal position. Furthermore, the load distribution can be adjusted easily so that the screw is more resistant to loosening and breaking.

Disadvantages of the abutment for cement:

Removal of the implant after cementation is very difficult. In the case of problems with the implant and screw, the superstructure must be cut and rebuilt. During cementation, cement may leak under the gingiva. It is difficult to clean; for this reason, the rate of biological complications is higher in cement-retained crowns than screw-retained crowns. (100, 101)

Implant body:

The implant body, also known as the fixture, is the implant piece that is meant to be implanted inside the bone and may expose minimally over the edge of the remaining bulge. A first-stage overlay is inserted at the top of the implant to protect soft tissue, bone, and debris from infiltrating the abutment attachment region during recovery (64). The phrase cover screw is used if the cover is screwed into place. A second-stage surgery is conducted to reveal the implant and connect the transepithelial part or abutment after a recommended recovery period to let a supportive interface grow (102, 64). This transepithelial part raises the implant above the soft tissue and permits a per mucosal barrier to form around it (103, 104). It is a temporary component that is installed with a permanent abutment once the gingival tissues have recovered. McKinney et al. (103) reviewed the nomenclature used to define the soft tissue contact covering dental implants and proposed per mucosal as a better phrase than transepithelial. In the lack of consistency in the terminology used to describe this aspect, the phrase the second stage per mucosal extension was chosen since it is the most accurate.

Types of Partial Dentures Supported by Implants

The prosthodontic classification proposed by Misch (105) is used for communication among implant team members. Accordingly, the final prosthesis was described depending on whether the quantity of hard and soft tissues replaced was removable or fixed. The first three classes are fixed types defining the appearance of the prosthesis. The last two classes are removable types defining the amount of the implant support, not the prosthesis' appearance.

Table 2. Classification of prosthodontics.

Type	**Definition**
Fixed prosthesis-1	The fixed prosthesis in which only the crown is replaced; seems like a natural tooth.
Fixed prosthesis-2	The fixed prosthesis that the crown and a piece of the root is replaced; crown contouring seems natural in the occlusal part but is extended or hyper contoured in the gingival side.
Fixed prosthesis-3	The fixed prosthesis that substitutes lost crowns, gingival colour, and a piece of the edentulous area; prosthesis most commonly employs denture teeth and acrylic gingiva but can be porcelain or metal.
Removable prosthesis-4	A removable prosthesis in which the implant totally supports an overdenture.
Removable prosthesis-5	A removable prosthesis that soft tissue and implant support the overdenture.

2.5. Dental Implant Success and Failure

The success and failure of dental implants are dynamic time-dependent circumstances depending on three main components: patient, dentist, and implant. The primary determinants of implant success are patient-related: bone quantity and quality, age, axial loading, and oral hygiene; physician-related: the dentist's experience; implant-related: the length and location of the implant. (106, 107) The main determinants of implant failure are patient-related: poor quality of bone, systemic diseases, recurrent infections, chronic periodontitis, advanced age, unfavourable patient habits, excessive and acentric loading, physician and implant-related: inappropriate prosthesis design and construction, improper prosthesis choice, implant location, short implants, absence/loss of implant compliance with hard and soft tissues. (106, 107)

Time-related assessment of implant failure involves early and late failures. Early failures are usually within the first year during the healing period, while late failures indicate the time after the osseointegration period. (107) Several reasons, as mentioned above, cause early failure; on the other hand, poor oral hygiene, infections, and mechanic complications due to occlusal overload and excessive stress usually contribute to late failures. (107)

2.6. Osseointegration and Implant Stability

Branemark first introduced the term osseointegration in 1977. (67) Osteointegration can be defined as the direct anchoring of the implant to the bone-by-bone formation around the implant without any fibrous tissue growth at the bone-implant interface. Today, osteointegration has started to be used in common sense with clinical success. (108) According to Albrektsson, osseointegration is defined as the direct link between bone and implant at the light microscope level. (109) There are six factors to ensure osteointegration: implant material and design, surface and bone quality, interventional technique, and implant loading procedure.

The main factors increasing the success of osteointegration (110):

- Microscopic and macroscopic characteristics of the implant surface
- Implant shape
- Grooves and steps of the implant
- Surface roughness (Osteoblasts adhere more easily to implants with a rough surface and increase the success of osteointegration)
- Atraumatic surgery
- Implant material's biocompatibility
- The health of the implant bed
- Bone quality
- Successful healing
- Prosthesis design and long-term loading phase

2.7. Loading Force and Screw Loosening

Screw Mechanics:

McGlumphy et al. (111) described a screw junction as two elements kept together by a screw, including an abutment and implant. Torque is used to fasten a screw, and the torque imparted generates a force within the screw known as the preload.

Tightening a screw causes it to elongate, causing tension. The screw's elastic recovery pushes the two sections together, providing a clamping force (112). The screw's preload caused by extension and elastic recovery is equivalent to the clamping force in quantity (111). A joint-separating force opposes the clamping force, attempting to split the screw connection. When the joint-separating forces acting on the screw connection are greater than the clamping forces holding the screw component together, screw loosening occurs (111). Too many pressures create sliding between the screw and bore threads, leading to reduced preload (113). It is not required to avoid separation forces; instead, they must be minimized (111). Screw loosening can be avoided by decreasing separation forces and increasing clamping forces.

When a physician tightens a screw's parts together, the tightening force causes a preload in the screw. The administered ıorque and other parameters such as screw alloy, screw head shape, and abutment interface affect the preload. The preload that has been produced is proportional to the applied torque. The physician may regulate the torque value, which can be replicated from one to another implant prosthesis. Insufficient torque may enable the connection to separate, resulting in screw exhaustion, loosening, and failure. A high torque may shred the screw threads (111). As the torque is increased, so does the preload. Raising the preload improves screw joint stability by raising the clamping limit that separate forces must cross to trigger screw releasing. The screw's full strength restricts the maximum torque that may be exerted. According to McGlumphy et al., the ideal torque value is 75 per cent of the torque required to produce screw failure. (111) Another factor influencing the quantity of energy delivered is the clinician's ability to generate torque. Torque can be delivered either manually or mechanically. Until mechanical torquing instruments were introduced into the field, implant pieces were tightened by hand. A beginner or unskilled physician frequently under-tightens the screws in an implant system. It was observed that the average screwdriver torque is just 10 N-cm (114). In a pilot investigation, it was reported that test participants with minimal implant expertise were typically unable to generate the appropriate tension to implant prosthesis–retaining notched gold screws (115). The researchers also discovered that experienced test individuals produced higher torque than was indicated, and none of the test groups made constant torque measurements.

Joint-Separating Forces:

The screw component of an implant prosthesis is continually affected by external joint-separating pressures. Off-axis occlusal interactions, lateral superficial interfaces, interproximal links between natural teeth and implants, protrusive connections, parafunctional tensions, and active frames that adhere to the implants are examples of intraoral separation pressures. External pressures that surpass the screw attachment preload cause the joint to become unsteady. The external stress quickly corrodes the preload, causing vibration and motion that leads to screw separation. When a screw joint loosens, it no longer performs its intended purpose and is regarded to have failed (113). The physician must understand the probable stresses operating on the screw joint to reduce or avoid screw loosening and other potential problems. Physicians are encouraged to employ a mechanical torque-applying tool to assure that implant pieces are consistently tightened to the prescribed torque levels indicated by implant makers.

Settling Effect:

The settling effect is a significant process that causes screw loosening in implant-supported prostheses. The settling effect (embedment relaxation), which is crucial for screw stability, is caused by no surface being smooth. It is relatively rough when inspected histologically, regardless of how well prepared an implant surface is. Due to this minimal roughness, neither of both surfaces are completely in touch with each other. Because the rough patches are the only interacting surfaces when the preliminary tightening tension is applied, they flatten beneath pressure and settle. Minimal movements between the surfaces tend to happen when the screw contact is exposed to external stresses, and the wearing on the contact points pushes the two surfaces closer. It has been suggested that settling causes a loss of two to ten per cent of the first preload (116). Consequently, the torque required to remove a screw is lower than the torque needed to install the screw (117). The amount of settling is determined by the initial surface roughness, hardness, and amount of loading forces, and rough surfaces and heavy external stresses accelerate settling. When the entire settling effect exceeds the screw's elastic stretch, the screw becomes free since no more contacting forces hold it together (118).

Thread friction is greater during the first tightening and releasing of a screw and diminishes with subsequent tightening and releasing cycles (118). Several researchers have proposed tightening implant screw joints after the first screw insertion and regularly after that (95, 119, 120). Bakaeen et al. (119) observed that when prosthetic gold screws were tightened to 10 N-cm per manufacturer's recommendations, the loosening torque of the various groups examined was around 2 to 3 N less than the tightening torque. These findings are consistent with those of Sakaguchi and Borgersen (116). They recorded a two to ten per cent decrease in preload during the first few seconds or minutes after tightening because of the settling effect. Following an in vitro experiment, Siamos et al. (120) proposed that retightening abutment screws 10 minutes after first torque administration must be occasionally conducted. The researchers also discovered that raising the torque levels for abutment screws over 30 N-cm may improve abutment-implant stability and prevent screw loosening. To decrease the settling effect, implant screws must be retightened 10 minutes following the first torque administration. (119, 120, and 95) This approach should be utilized regularly in clinical settings.

2.8. Dental Torque Measurement

2.8.1. Manual Torque Wrench

Screws of various shapes and materials are used to link dental prostheses to implants and abutments. It was noticed that utilizing the manufacturer's suggested design of screw and metal type for each implant and abutment is better. (121) Tightening screws to the proper torque value is an essential aspect of this operation. Evidence shows that not enough torquing an implant screw can result in screw loosening, breakage, failure (122), and, eventually, prosthesis failure. Screw distortion, screw loosening, and breakage can all result from torquing more than needed. (123) On implant screws and abutments, hand-held screwdrivers have been demonstrated to give unpredictable torque levels (115). When experienced clinicians utilized hand-held drivers to create 32 N-cm of torque, one research showed values ranging from 8.2 to 36.2 N-cm. (124) Dellinges and Tebrock tested the torque delivered to a hex wrench by dental students; the average torque generated was 11.5 N-cm and depended on the operator's level of expertise. (125) They supported the fact that just a few screws could be properly tightened manually. As a result of these factors, it is now common practice to tighten implant screws using mechanical torque-limiting devices in order to apply the required torque to screws. This happens when abutments are attached to implants as well as when screw-retained prostheses are inserted.

There are minimum two types of mechanical torque-limiting devices, and different nomenclature is used for their description. In other sectors, the first kind, known as a click torque wrench, employs a ball locking mechanism to release the lever arm and restrict the torque delivered at the specified torque. A spring holds the ball in position once it has been crushed into a spherical receiver (detent). When the required torque is administered, the ball slides out of the lock, and the wrench's head swings to the edge or switches. This "friction" type or click torque wrench shall be referred to as a toggle-type wrench. (126) The beam type or "spring" torque-limiting mechanism is another form of mechanical torque device. When force is applied to the beam, it diverts, and the spring reaction torques the screw. The energy used is determined by how far the beam is deflected; most dental devices contain a scale with indications showing the applied load.

Another benefit of this equipment is that it can apply numerous torques with the same device, whereas toggle-type instruments can only use one quantity. The deflected beam apparatus shall be referred to as a beam torque wrench. Some papers investigated the dependability of mechanical torque devices. Standlee et al. tested three mechanical devices to measure torque application accuracy. (127) They came to conclusion that both toggle and beam torque wrenches were within ten per cent of torque goal values.

It has to be mentioned that the wrenches utilized in this investigation were brand new and had never been used in a clinical setting. The researchers also determined that they created more consistent torque when wrenches were operated slowly. According to new findings, the beam torque wrench provides torque closer to desired values than toggle-type torque wrenches. The variance for the beam devices was 0.82 N-cm, whereas it was 3.83 N-cm for the toggle-type devices. All of the gadgets tested in this study were also brand new.

The research, however, shows that clinical usage and sterilization may affect torque levels (125), and torque values may fluctuate after several uses. (128) Gutierrez et al. observed the highest variances of up to 58 per cent of stated values in a survey of clinically used instruments and one 10 N-cm toggle-type wrenches that applied 455 per cent of the declared torque amount. (129) In another investigation using beam torque wrenches, scientists determined a minimal drop in applied torque following the wrenches were used and disinfected up to 1000 times. Torque values reduced by 1.5 N-cm when compared to newer wrenches, which constituted a significant difference. (128)

Differences in torque instruments are also documented in other fields, like orthopaedics, with observed torque being within ten per cent of the intended value in 69.2% of torque implementations. (130, 131) Clinicians may try to apply a specified torque through finger pressure rather than a mechanical instrument. This strategy has been demonstrated to be very unpredictable. (132) Even if a small physician can deliver the torque with the requisite force, the applied energy is not constant. (121) According to other investigations, finger pressure is insufficient to implement the appropriate preload to the locking mechanism. (133) According to research, the quantity of torque delivered with finger pressure on an implant wrench averaged 11.55 N-cm, which was far under several of the needed 20 and 30 N-cm application criteria. (114)

Different torque devices, including electronic torque controllers, have shown inadequate variability, with values as high as 165 per cent of the goal. (133, 134) The literature reveals significant differences among torque wrenches when used collectively. The objective of this paper was to determine the constancy of force generated by a group of torque-limiting mechanisms used at a dentistry school in the United States.

2.8.2. Automatic Prosthodontic Screwdriver

Manufacturers have recently introduced modern electronic torque drivers to keep up with technical improvements in dentistry, and demand is growing. The electronic torque driver uniformly applies the desired torque value to the abutment screw digitally. The torque level is displayed on the LCD panel. It outperforms manual systems in terms of accuracy and ease. Electronic torque screwdrivers were designed to alleviate the inevitable tightening torque mistakes in manual torque and offer a standardized tightening torque application. Within the constraints of this *in vitro* experiment, all three electronic torque drivers exhibited substantial variations in unscrewing torque values. The tightening and unscrewing torque varied slightly, with the majority of the unscrewing torque being lower than the tightening torque. SAESHIN (33.1 ± 2.4 N-cm) had the most precise unscrewing torques at 35 N-cm, and NSK (15.1 ± 0.9 N-cm and 24.0 ± 1.4 N-cm) had correct loosening torques at 15 N-cm and 25 N-cm. Because the loosening torque varies based on the tightening torques, it is advised that the electronic torque driver be calibrated regularly (135).

3. MATERIALS AND METHODS

3.1. Study Design

The study was conducted in Yeditepe University, in the laboratory of the Prosthetic Dental Treatment Department. All interventions were performed on an implant model designed for educational purposes.

3.2. Implants and Abutment Systems, and Torque Devices

20 Mode implants (Mode Medikal Ltd, Istanbul, Turkey) and 20 Alpha Dent implants (Alpha Dent Implants Ltd, Pforzheim Baden-Württemberg, Germany), and cemented abutments and screws compatible with implants were used in this study. The implants included Mode implants with 3.3 mm in diameter and 10 mm in length and straight abutments with 3.7 mm in diameter and 9 mm in length; Alpha Dent implants with 3.3 in diameter and 10 mm in length and straight abutments with 3.75 mm in diameter and 9 mm in length.

Table 3. Implants and abutments features.

Implant	Diameter and Height	Abutment Type	Abutment Diameter	Abutment Height	Abutment Gingival Level
Mode Level Implant	3.3/10 mm	Straight	3.7 mm	10 mm	0 mm
Alpha Dent Implant Classic	3.3/10 mm	Straight	3.75 mm	9 mm	0 mm

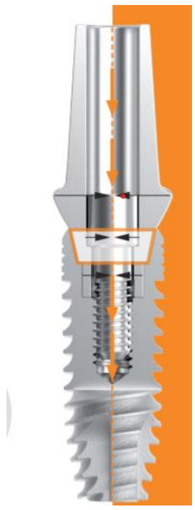

Figure 8.: Mode Bone Level implant system and its internal structure

Figure 9.: Alpha Dent Classic implant system and its internal structure.

Implants were fixed by embedding acrylic in plastic containers to accurately measure the tightening and unscrew torque values (Figure 10.). Implants were placed in acrylic blocks that have 3 cm length and 3 cm wide at 3 cm intervals with the implant-abutment junction levels above the upper level of acrylic before the acrylic was fully polymerized. We used self-cure acrylic in our study. All implants were placed in the acrylic blocks to form a right angle with the horizontal plane. Parallelometer was used to place implants perpendicular to the ground plane. We used eight acrylic blocks with five implants in each.

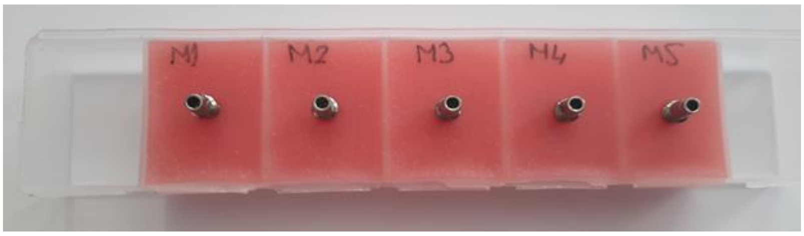

Figure 10. Implants in the acrylic blocks.

An automatic torque device, IA-400 Prosthodontic Screwdriver (W&H Dentalwerk Bürmoos GmbH, Bürmoos, Austria) (Figure 11.a), and implant brands' own manual torque wrenches (Figure 11.b) were used to impart tightening and loosening torque to the abutments and screws. Ten implants of each brand were reserved for the automatic torque device and 10 for manual wrenches.

Figure 11.a An automatic torque wrench: IA-400 W&H Prosthodontic screwdriver.

Figure 11.b Manual torque wrenches. Left: Alpha Dent; Right: Mode Implant

Measurements of torque values were made with a torque measuring device, Beta 580/25F 1/4" drive dial torque screwdriver (Beta Tools, Beta Utensili S.P.A., Sovico (MB), Italy) (Figure 12.) Beta 580/25F 1/4" drive dial torque screwdriver has 0-250 N-cm torque range (+/-) 6% accuracy, for the right hand and left-hand tightening. In addition to being light, it stands out with its durability even under the toughest working conditions. It has 250 mm in length. The dial on these controllers makes it easy to see the amount of torque being applied.

Figure 12. Torque measuring device: Beta 580/25F 1/4" Drive Dial Torque Screwdriver (Beta Utensili S.P.A, Sovico, Italy); 0 - 250 N-cm torque range with ± 6% torque accuracy for right-hand and left-hand tightening.

3.3. Study Plan

A total of 40 implants, abutments, and screws were divided into two main groups according to the brands (Alpha Dent n=20; Mode n=20) used in this study to eliminate the rate of fraying. Then these two groups were divided into two subgroups for automatic (n=10) and manual (n=10) torque spanner in both implant brands. After that, with a manual or automatic torque wrench, ten implants, ten abutments, and ten screws of the same brand in the subgroups were tightened at 15 N-cm, 25 N-cm and 35 N-cm, respectively at five times. Finally, the screws were loosened with a torque measuring device, and the unscrewing torque values were noted.

Implants were fixed by embedding acrylic in plastic containers to accurately measure the tightening and unscrew torque values. Implants were placed in acrylic blocks at 3 cm intervals with the implant-abutment junction levels above the upper level of acrylic before the acrylic was fully polymerized. All implants were placed in the acrylic blocks to form a right angle with the horizontal plane. Paralelometer was used to place implants perpendicular to the ground plane.

3.4. Study Groups

The flowchart of the study is presented in Figure 12. The abutments were attached to the implant with a manual or automatic torque wrench without applying any agent to its surface at 15, 25, and 35 N-cm of torque values. Then, the screws were unscrewed with the torque measuring instrument, and the value was saved to the computer. This process was repeated five times for each abutment. Then the arithmetic mean values of all five measurements were included in the final analysis.

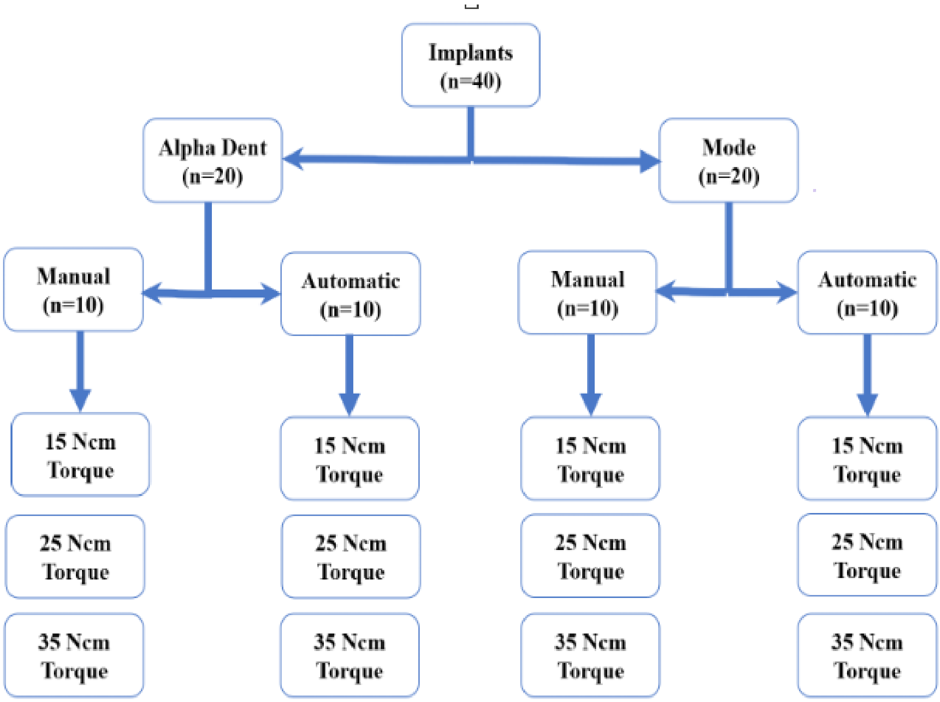

Figure 13. Flowchart of the study.

Experimental Group	Implant	Torque Value	Manuel	Automatic
Group 1	Alpha Dent	15 N-cm	+	-
Group 2	Alpha Dent	15 N-cm	-	+
Group 3	Mode	15 N-cm	+	-
Group 4	Mode	15 N-cm	-	+
Group 5	Alpha Dent	25 N-cm	+	-
Group 6	Alpha Dent	25 N-cm	-	+
Group 7	Mode	25 N-cm	+	-
Group 8	Mode	25 N-cm	-	+
Group 9	Alpha Dent	35 N-cm	+	-
Group 10	Alpha Dent	35 N-cm	-	+
Group 11	Mode	35 N-cm	+	-
Group 12	Mode	35 N-cm	-	+

Table 4. Study Group. The "+" sign represents which torque method is used for which brand and torque value

3.4.1. Alpha Dent Implant - 15 N-cm Manuel Torque Device

Ten Alpha Dent implants were placed vertically in the acrylic block. The abutments were attached to the implant with a manual torque wrench without applying any agent to its surface at 15 N-cm of torque value. Then, the screws were unscrewed with a torque measuring instrument, and the value was saved to the computer. This process was repeated five times for every ten implants.

3.4.2. Alpha Dent Implant - 15 N-cm Automatic Torque Device

Ten Alpha Dent implants were placed vertically in the acrylic block. The abutments were attached to the implant with an automatic torque device without applying any agent to its surface at 15 N-cm of torque value. Then, the screws were unscrewed with a torque measuring instrument, and the value was saved to the computer. This process was repeated five times for every ten implants.

3.4.3. Mode Implant - 15 N-cm Manuel Torque Device

Ten Mode implants were placed vertically in the acrylic block. The abutments were attached to the implant with a manual torque wrench without applying any agent to its surface at 15ncm of torque value. Then, the screws were unscrewed with a torque measuring instrument, and the value was saved to the computer. This process was repeated five times for every ten implants.

3.4.4. Mode Implant - 15 N-cm Automatic Torque Device

Ten Mode implants were placed vertically in the acrylic block. The abutments were attached to the implant with an automatic torque device without applying any agent to its surface at 15ncm of torque value. Then, the screws were unscrewed with a torque measuring instrument, and the value was saved to the computer. This process was repeated five times for every ten implants.

3.4.5. Alpha Dent Implant - 25 N-cm Manuel Torque Device

Ten Alpha Dent implants were placed vertically in the acrylic block. The abutments were attached to the implant with a manual torque wrench without applying any agent to its surface at 25 N-cm of torque value. Then, the screws were unscrewed with a torque measuring instrument, and the value was saved to the computer. This process was repeated five times for every ten implants.

3.4.6. Alpha Dent Implant - 25 N-cm Automatic Torque Device

Ten Alpha Dent implants were placed vertically in the acrylic block. The abutments were attached with an automatic torque device to the implant without applying any agent to its surface at 25 N-cm of torque value. Then, the screws were unscrewed with a torque measuring instrument, and the value was saved to the computer. This process was repeated five times for every ten implants.

3.4.7. Mode Implant - 25 N-cm Manuel Torque Device

Ten Mode implants were placed vertically in the acrylic block. The abutments were attached to the implant with a manual torque wrench without applying any agent to its surface at 25 N-cm of torque value. Then, the screws were unscrewed with a torque measuring instrument, and the value was saved to the computer. This process was repeated five times for every ten implants.

3.4.8. Mode Implant - 25 N-cm Automatic Torque Device

Ten Mode implants were placed vertically in the acrylic block. The abutments were attached with an automatic torque device to the implant without applying any agent to its surface at 25 N-cm of torque value. Then, the screws were unscrewed with a torque measuring instrument, and the value was saved to the computer. This process was repeated five times for every ten implants.

3.4.9. Alpha Dent Implant - 35 N-cm Manuel Torque Device

Ten Alpha Dent implants were placed vertically in the acrylic block. The abutments were attached to the implant with a manual torque wrench without applying any agent to its surface at 35 N-cm of torque value. Then, the screws were unscrewed with a torque measuring instrument, and the value was saved to the computer. This process was repeated five times for every ten implants.

3.4.10. Alpha Dent Implant - 35 N-cm Automatic Torque Device

Ten Alpha Dent implants were placed vertically in the acrylic block. The abutments were attached to the implant with an automatic torque device without applying any agent to its surface at 35 N-cm of torque value. Then, the screws were unscrewed with a torque measuring instrument, and the value was saved to the computer. This process was repeated five times for every ten implants.

3.4.11. Mode Implant - 35 N-cm Manuel Torque Device

Ten Mode implants were placed vertically in the acrylic block. The abutments were attached to the implant with a manual torque wrench without applying any agent to its surface at 35 N-cm of torque value. Then, the screws were unscrewed with a torque measuring instrument, and the value was saved to the computer. This process was repeated five times for every ten implants.

3.4.12. Mode Implant - 35 N-cm Automatic Torque Device

Ten Mode implants were placed vertically in the acrylic block. The abutments were attached to the implant with an automatic torque device without applying any agent to its surface at 35ncm of torque value. Then, the screws were unscrewed with a torque measuring instrument, and the value was saved to the computer. This process was repeated five times for every ten implants.

3.5. Statistics

The statistical data were analysed using the software SPSS Statistics for Windows version 25.0, 2017 (Armonk, NY: IBM Corp.). The Kolmogorov Smirnov test was used to analyse the normality of the data. Parametric tests were used where the data were normally distributed, and a nonparametric equivalent to the parametric hypothesis test was used if the assumptions could not be met for the parametric test. The measurements of unscrewing torque values were evaluated with the Mann Whitney-U test or independent sample t-test, where possible. The difference between the measurements was analysed with a one-way analysis of variance (one-way ANOVA), where the data were normally distributed. A *post hoc* Tukey’s honestly significant difference (Tukey HSD) test was used to identify which group pairing led to this significant difference if there was a statistically significant difference in the multiple group comparisons. Descriptive data were presented as mean ± standard deviation (SD) or median (interquartile range (IQR) 25-75), and the results were evaluated within the 95% confidence interval (CI). A p-value <0.05 was considered statistically significant.

4. RESULTS

4.1. Comparison of Alpha Dent and Mode implants with their own ratchet

In this study, ten abutments of Alpha Dent implants were tightened at three different unscrewing values. Each abutment was torqued five times, a total of fifty times for each torque value, with each **brand's own ratchet**. Subsequently, unscrewing values obtained with a torque measuring instrument was recorded. Then, the same process was repeated for the abutments of the Mode brand implants. Obtained values were statistically analysed with the one-sample t-test.

In the torque measurement of 15 N-cm with Alpha dent implant, the lowest unscrewing value was measured as 10 N-cm, while the highest unscrewing value was measured as 22 N-cm. With a torque measurement of 15 N-cm in the Mode implant, the lowest unscrewing value was measured as 10 N-cm, while the highest unscrewing value was measured as 16 N-cm. At a 15 N-cm unscrewing value of 15 N-cm, the unscrewing value obtained from Alpha dent implants ($\bar{x}$ = 16.7±2.6 N-cm) was 35.7% higher than the unscrewing value from Mode implants ($\bar{x}$ = 12.3±1.5 N-cm). This result was statistically significant. ($p<0.05$)

In the torque measurement value of 25 N-cm with Alpha Dent implant, the lowest unscrewing value was measured as 21 N-cm, while the highest unscrewing value was measured as 27 N-cm. With a torque measurement of 25 N-cm in the Mode implant, the lowest unscrewing value was measured as 19 N-cm, while the highest unscrewing value was measured as 29 N-cm. The unscrewing value of Alpha dent implants at 25 N-cm unscrewing torque ($\bar{x}$ = 24.2±1.4 N-cm) was 4.7% higher than the unscrewing value of Mode implants ($\bar{x}$ = 23.1±2.6 N-cm). This difference was not statistically significant ($p>0.05$).

In the 35 N-cm torque measurement with Alpha dent implant, the lowest unscrewing value was measured as 30 N-cm, while the highest unscrewing value was measured as 40 N-cm. In the 35 N-cm torque measurement with the Mode implant, the lowest unscrewing value was measured as 27 N-cm, while the highest unscrewing value was measured as 40 N-cm. At 35 N-cm unscrewing value, the unscrewing value obtained from Alpha dent implants ($\bar{x}$ = 34.9±2.1 N-cm) was 5.1% higher than the unscrewing value from Mode implants ($\bar{x}$ = 33.2±3 N-cm). This difference was statistically insignificant. ($p>0.05$) (Table 5.)

Table 5. Comparison of unscrewing torque values between two implant brands' own rachet of 15 N-cm, 25 N-cm, 35 N-cm.

Value of tightening torque	Implant	n	x̄ Value of unscrewing	sd±	se	min	max	skewness	p
15 N-cm	ALPHA	50	16.7	2,6	0.37	10	22	0,01	0.019*
	MODE	50	12.3	1,5	0.20	10	16	0.41	
25 N-cm	ALPHA	50	24.2	1,4	0.19	21	27	-0.20	0.137
	MODE	50	23.1	2,6	0.36	19	29	0.48	
35 N-cm	ALPHA	50	34.9	2,1	0.29	30	40	0.27	0.622
	MODE	50	33.2	3,0	0.43	27	40	0.54	

4.2. Comparison of Alpha Dent and Mode implants with automatic screwdriver

Ten abutments of Alpha Dent implants were tightened at three different unscrewing torque values. Each abutment was torqued five times with an **automatic screwdriver**, a total of fifty times for each torque value. Subsequently, unscrewing values obtained with a torque measuring instrument was recorded. Then the same process was repeated for the abutments of the Mode implants. Obtained values were statistically analysed with the one-sample t-test.

In the torque measurement value of 15 N-cm with the Alpha dent implant, the lowest unscrewing value was measured as 11 N-cm, while the highest unscrewing value was measured as 18 N-cm. With the Mode implant at the 15 N-cm torque measurement, the lowest unscrewing value was measured as 9 N-cm, while the highest unscrewing value was measured as 18 N-cm. The unscrewing value obtained from Alpha dent implants at the 15 N-cm unscrewing value ($\bar{x}$ = 14, ± 1.7 N-cm) was 12.9% higher than the unscrewing value from Mode implants ($\bar{x}$ = 12.4, ± 2.3 N-cm). This difference was not statistically significant. ($p>0.05$)

In the 25 N-cm torque measurement with Alpha dent implant, the lowest unscrewing value was measured as 21 N-cm, while the highest unscrewing value was measured as 28 N-cm. In the 25 N-cm torque measurement with the Mode implant, the lowest unscrewing value was measured as 17 N-cm, while the highest unscrewing value was measured as 28 N-cm. At the 25 N-cm unscrewing value, the removal value from Alpha dent implants ($\bar{x}$ = 23.6, ±1.8) was 9.8% higher than the unscrewing value from Mode implants ($\bar{x}$ = 21.5, ±2.8). This difference is statistically insignificant. ($p>0.05$)

In the 35 N-cm torque measurement with Alpha dent implant, the lowest unscrewing value was measured as 30 N-cm, while the highest unscrewing value was measured as 40 N-cm. In the 35 N-cm torque measurement with the Mode implant, the lowest unscrewing value was measured as 28 N-cm, while the highest unscrewing value was measured as 40 N-cm. At 35 N-cm unscrewing value, the unscrewing value obtained from Alpha dent implants ($\bar{x}$ = 33.4, ±2.2) was 2.8% higher than the removal value obtained from Mode implants ($\bar{x}$ = 32.5, ±3). This difference was not statistically significant ($p>0.05$). (Table 6.)

Table 6. Comparison of unscrewing torque values between two implant brands with an automatic screwdriver of 15 N-cm, 25 N-cm, 35 N-cm.

Value of tightening torque	**Implant**	**n**	**$\bar{x}$ Value of unscrewing**	**sd±**	**se**	**min**	**max**	**skewness**	**p**
15 N-cm	ALPHA	50	14.0	1,7	0.24	11	18	0.46	0.760
	MODE	50	12.4	2,3	0.32	9	18	0.64	
25 N-cm	ALPHA	50	23.6	1,8	0.25	21	28	0.51	0.592
	MODE	50	21.5	2,8	0.39	17	28	0.32	
35 N-cm	ALPHA	50	33.4	2,2	0.31	30	40	0.53	0.825
	MODE	50	32.5	3,0	0.42	28	40	0.59	

4.3. Comparison of manual and automatic torque values at Alpha Dent implant

Ten abutments of **Alpha Dent** implants were tightened at three different unscrewing values. Each abutment was torqued five times for each torque value, a total of fifty times with an automatic screwdriver and the brand's own ratchet. Then, unscrewing values were recorded by unscrewing with a torque measuring instrument. Obtained values were statistically analysed with the one-sample t-test.

In Alpha dent implant, in 15 N-cm torque measurement with the manual ratchet, the lowest unscrewing value was measured as 10 N-cm, while the highest unscrewing value was measured as 22 N-cm. In the 15 N-cm torque measurement with the automatic screwdriver, the lowest unscrewing value was measured as 11 N-cm, while the highest unscrewing value was measured as 18 N-cm. At the 15 N-cm unscrewing value, the unscrewing value obtained from the manual ratchet ($\bar{x}$ = 16.7, ± 2.6 N-cm) was found to be 19.3% higher than the unscrewing value from the automatic screwdriver ($\bar{x}$ = 14, ± 1.7 N-cm). This difference was statistically significant ($p<0.05$).

In Alpha dent implant, in 25 N-cm torque measurement with the manual ratchet, the lowest unscrewing value was measured as 21 N-cm, while the highest unscrewing value was measured as 27 N-cm. In the 25 N-cm torque measurement with the automatic screwdriver, the lowest unscrewing value was measured as 21 N-cm, while the highest unscrewing value was measured as 28 N-cm. At the 25 N-cm unscrewing value, the unscrewing value obtained from the manual ratchet ($\bar{x}$ = 24.2, ± 1.4 N-cm) was found to be 2.5% higher than the unscrewing value from the automatic screwdriver ($\bar{x}$ = 23.6 ± 1.8 N-cm). This difference was not statistically significant ($p>0.05$).

In the Alpha dent implant, in the 35 N-cm torque measurement with the manual ratchet, the lowest unscrewing value was measured as 30 N-cm, while the highest unscrewing value was measured as 40 N-cm. In the 35 N-cm torque measurement with the automatic screwdriver, the lowest unscrewing value was measured as 30 N-cm, while the highest unscrewing value was measured as 40 N-cm. At the 35 N-cm unscrewing value, the unscrewing value obtained from the manual ratchet ($\bar{x}$ = 34.9, ± 2.1 N-cm) was found to be 4.5% higher than the unscrewing value from the automatic screwdriver ($\bar{x}$ = 33.4, ± 2.2 N-cm). This difference was statistically insignificant ($p>0.05$). (Table 7.)

Table 7. Comparison of manual and automatic unscrewing torque value at Alpha Dent implant of 15 N-cm, 25 N-cm, 35 N-cm**.**

Value of tightening torque	**Device**	**n**	**x̄ Value of unscrewing**	**sd ±**	**se**	**min**	**max**	**skewness**	**p**
15 N-cm	MANUEL	50	16.7	2,6	0.37	10	22	0,01	0.032*
	AUTOMATIC	50	14.0	1,7	0.24	11	18	0.46	
25 N-cm	MANUEL	50	24.2	1,4	0.19	21	27	-0.20	0.112
	AUTOMATIC	50	23.6	1,8	0.25	21	28	0.51	
35 N-cm	MANUEL	50	34.9	2,1	0.29	30	40	0.27	0.517
	AUTOMATIC	50	33.4	2,2	0,31	30	40	0.53	

4.4. Comparison of manual and automatic torque values at Mode implant

Ten abutments of **Mode** implants were tightened at three different unscrewing values. Each abutment was torqued five times for each torque value, a total of fifty times with an automatic screwdriver and the brand's own ratchet. Then, unscrewing values were recorded by unscrewing with a torque measuring instrument. Obtained values were statistically analysed with the one-sample t-test.

In Mode implant, in the 15 N-cm torque measurement with the manual ratchet, the lowest unscrewing value was measured as 10 N-cm, while the highest unscrewing value was measured as 16 N-cm. In the 15 N-cm torque measurement with the automatic screwdriver, the lowest unscrewing value was measured as 9 N-cm, while the highest unscrewing value was measured as 18 N-cm. At the 15 N-cm unscrewing value, the unscrewing value obtained from the manual screwdriver ($\bar{x}$ = 12.3, ± 1.5 N-cm) was found to be 0.8% lower than the unscrewing value from the automatic screwdriver ($\bar{x}$ = 12.4, ± 2.3 N-cm). This difference was statistically insignificant ($p>0.05$).

In Mode implant, in the 25 N-cm torque measurement with the manual ratchet, the lowest unscrewing value was measured as 19 N-cm, while the highest unscrewing value was measured as 29 N-cm. In the 25 N-cm torque measurement with the automatic screwdriver, the lowest unscrewing value was measured as 17 N-cm, while the highest unscrewing value was measured as 28 N-cm. At the 25 N-cm unscrewing value, the unscrewing value obtained from the manual screwdriver ($\bar{x}$ = 23.1, ± 2.6 N-cm) was found to be 7.4% lower than the unscrewing value from the automatic screwdriver ($\bar{x}$ = 21.5, ± 2.8 N-cm). This difference was statistically insignificant ($p>0.05$).

In Mode implant, in the 35 N-cm torque measurement with the manual ratchet, the lowest unscrewing value was measured as 27 N-cm, while the highest unscrewing value was measured as 40 N-cm. In the 35 N-cm torque measurement with the automatic screwdriver, the lowest unscrewing value was measured as 28 N-cm, while the highest unscrewing value was measured as 40 N-cm. At the 35 N-cm unscrewing value, the unscrewing value obtained from the manual screwdriver ($\bar{x}$ = 33.2, ± 3 N-cm) was found to be 2.2% lower than the unscrewing value from the automatic screwdriver ($\bar{x}$ = 32.5, ± 3 N-cm). This difference was statistically insignificant ($p>0.05$). (Table 8.)

Table 8. Comparison of manual and automatic unscrewing torque value at Mode implant of 15 N-cm, 25 N-cm, 35 N-cm.

Value of tightening torque	Device	n	$\bar{x}$ Value of unscrewing	sd±	se	min	max	skewness	p
15 N-cm	MANUEL	50	12.3	1,5	0.20	10	16	0.41	0.598
	AUTOMATIC	50	12.4	2,3	0.32	9	18	0.64	
25 N-cm	MANUEL	50	23.1	2,6	0.36	19	29	0.48	0.453
	AUTOMATIC	50	21.5	2,8	0.39	17	28	0.32	
35 N-cm	MANUEL	50	33.2	3,0	0.43	27	40	0.54	0.761
	AUTOMATIC	50	32.5	3,0	0.42	28	40	0.59	

4.5. Comparison of all torque values obtained from manual and automatic torque devices

In each of the three different torque values, the value obtained from the manual rachets was higher than the values obtained from the automatic screwdrivers, and the statistically significant difference was found only in the 15 N-cm unscrewing value.

In the 15 N-cm torque measurement with the manual ratchet, the lowest unscrewing value was measured as 10 N-cm, while the highest unscrewing value was measured as 22 N-cm. In the 15 N-cm torque measurement with the automatic screwdriver, the lowest unscrewing value was measured as 9 N-cm, while the highest unscrewing value was measured as 18 N-cm. At the 15 N-cm unscrewing value, the unscrewing value obtained from the manual ratchet ($\bar{x}$ = 14.5, ± .1 N-cm) was found to be 9.2% lower than the unscrewing value from the automatic screwdriver ($\bar{x}$ = 13.2, ± 2.2 N-cm). This difference was statistically significant ($p<0.05$).

In the 25 N-cm torque measurement with the manual ratchet, the lowest unscrewing value was measured as 19 N-cm, while the highest unscrewing value was measured as 29 N-cm. In the 25 N-cm torque measurement with the automatic screwdriver, the lowest unscrewing value was measured as 17 N-cm, while the highest unscrewing value was 28 N-cm. At the 25 N-cm unscrewing value, the unscrewing value obtained from the manual ratchet ($\bar{x}$ = 23.6, ± 2.1 N-cm) was found to be 4.4% higher than the unscrewing value from the automatic screwdriver ($\bar{x}$ = 22.6, ± 2.6 N-cm). This difference was not statistically significant. ($p>0.05$)

In the 35 N-cm torque measurement with the manual ratchet, the lowest unscrewing value was measured as 27 N-cm, while the highest unscrewing value was measured as 40 N-cm. In the 35 N-cm torque measurement with the automatic screwdriver, the lowest unscrewing value was measured as 28 N-cm in, while the highest unscrewing value was measured as 40 N-cm. At 35 N-cm unscrewing value, the unscrewing value obtained from the manual ratchet ($\bar{x}$ = 34 ± 2.7 N-cm) was found to be 3.3% higher than the unscrewing value from the automatic screwdriver ($\bar{x}$ = 32.9, ± 2.7 N-cm). This difference was not statistically significant ($p>0.05$). (Table 9.)

Table 9. Comparison of manual and automatic unscrewing torque values of 15 N-cm, 25 N-cm, 35 N-cm.

Value of tightening torque	Device	n	x̄ Value of unscrewing	sd±	se	min	max	skewness	p
15 N-cm	MANUEL	100	14.5	3,1	0.30	10	22	0.56	0,002*
	AUTOMATIC	100	13.2	2,2	0.21	9	18	0.22	
25 N-cm	MANUEL	100	23.6	2,1	0.21	19	29	-0.04	0.051
	AUTOMATIC	100	22.6	2,6	0.25	17	28	-0.14	
35 N-cm	MANUEL	100	34.0	2,7	0.27	27	40	-0.25	0.978
	AUTOMATIC	100	32.9	2,7	0.26	28	40	0.40	

5. DISCUSSION

Dental implants have been widely used for more than 30 years in single, partial, and complete tooth loss cases. Although many clinics reported high success, early or late implant losses are still inevitable. Late losses occur after prosthesis construction and are generally associated with biomechanical complications. Biomechanics from implant losses the mechanism responsible is still not fully understood. Heavy economic conditions in our country restrict the application of oral implantology. By considering many factors, the physician's duty who will perform such an application should be to take precautions to minimize the possibility of failure.

In the patient to be implanted, all information should be obtained in full with the clinical and radiological examination in the planning phase before the application, and a treatment plan should be created in light of this information. In long-term control studies of implant success, it has been determined that many complications may occur following the prosthetic phase. These complications; fractures in implant components, fractures in the superstructure, abutment loosening, marginal bone loss and osteointegration impairment. (106)

Having information about the complications that may occur during implant applications is an essential part of treatment planning, patient-physician relationship and post-treatment care. Knowing these complications and taking precautions against them will increase the success of the implant. Implant failure can be examined in two parts as failures occur before and after applying the prosthesis. Failures before the prosthesis are usually caused by surgical reasons. (136) The reasons for the post-prosthetic loss are; poor oral hygiene, improper loading and superstructure incompatibilities. Implant size, diameter and bone quality are also factors affecting success. The quantity and quality of bone surrounding the implant; osteointegration affects the shape and contour of the soft tissue and, therefore, aesthetics. The amount of hard and soft tissue surrounding the implant and the type and position of the implant affect the function and aesthetic result.

Late complications in implant treatments vary in different prosthesis types. Studies examining failure usually include follow-up periods of five to ten years. In addition, follow-ups longer than ten years are also limited.

In the review by Zembic et al. in 2014 (137), the implant survival rate was 96.9%, and the prosthesis survival rate was 95.6% in the five-year period. The rate of technical complications was 11.8%, biological complications were 6.4%, and aesthetic complications were 0.9%. The most common technical complication was abutment screw loosening, with a rate of 4.6%. In addition to these studies, longer-term follow-up studies were also available in the current literature. In their long-term follow-up study, the implant survival rate was 91.3% over a 16-years period, and the prosthesis survival rate was 73%. Technical complications were determined as 35.6%, biological complications 20.3% and aesthetic complications 23.7%. Among the technical complications, the most observed was abutment screw loosening, with a rate of 25.4%.

In 2012, Jung et al. (138), in their review, the survival rate of implants was 97.2% at the end of 5 years and regressed to 95.2% towards the tenth year. The survival rate in implant-supported single crowns decreased to 96.3% at the end of the first five years and 89.4% at the end of ten years. In total, the rate of technical complications was 16.76%. Biological complications were seen at a rate of 7.1%, and aesthetic complications at a rate of 7.1%. The most observed complication was screw loosening, with a rate of 8.8%. In this study, we investigated whether there was a difference between two different instruments to reduce the loosening of the abutment screw, which was the most common technical complication.

When the studies summarized above were examined, it was observed that biological complications were less than mechanical complications. This fact shows that the failure of implant-supported prostheses is mostly in the late period. When the late failures were evaluated in themselves, screw loosening was the most common late failure. (139, 140, 141) Apart from these studies, it was emphasized that screw loosening was the most observed complication. Screw loosening was observed more in fixed prostheses. However, the incidence of single-tooth implant-supported fixed restorations was higher than fixed partial dentures. When it was evaluated according to the type of retention in fixed prostheses, it was observed with a higher frequency in screwed restorations than in cement-retained restorations. In addition, it was reported that the frequency of screw loosening was higher in external hexagon connections. (142)

The modulus of elasticity of auto-polymerized acrylic was approximately 12 GPa (143), and epoxy resin was 21 GPa (144). Auto-polymerized acrylic was used in most of the studies in which the removal torque values were measured. (143, 145, 146, 147, 148-150, 151-153) In our study, auto-polymerized acrylic was used to best imitate the implant condition in the bone. In addition, the cost of auto-polymerized acrylic was lower than other options, and the polymerization time was shorter, which has been the reason for preference. So, we used auto-polymerized acrylic in our study.

Before using mechanical torque application tools, the final tightening was done by hand. In a study by Dellinges and Tebrock in 1993 (29) on this subject on second-year dentistry students, it was determined that the maximum torque value that could be applied by hand was 11.55 N-cm. Gross et al., in 1999 (154) reported in their study on physicians with three or more years of experience in making implant-supported prostheses that the maximum tightening values managed from 9.4-19.9 N-cm, and the screw tightening values in clinical practice varied between 7.0-14.6 N-cm. Dellinges and Tebrock (29) stated that the average torque values applied with the implant wrench were only 10 N-cm. Hill et al. (132) conducted a study in 2007 on torque values that could be applied manually by dentists with and without experience for more than 20 years. In this study, the mean value was 12.9 N-cm in physicians with 20 years or less experience and 13.5 N-cm in senior physicians. Torque values applied manually gradually differ in the studies in the literature. Mason tightened the abutment screw with 20 N-cm, and Cano-Batalla tightened to a torque of 35 N-cm. That is why we worked at three different torque values (15 N-cm, 25 N-cm, 35 N-cm) in our study.

Alikhasi et al. in 2017 showed that together with the position of the implant, the type and size of the implant wrench changed the applied torque value. (155) Additionally, the highest torque value was obtained with long wrenches in anterior implants. (155) In our study, the implants were placed in the same pattern to eliminate these factors, and the torque was not done manually but with a manual ratchet and automatic screwdriver.

Stuker et al. (156) compared the effects of three different abutment screw materials on unscrewing torque values in 2008. The same implants and abutments in their work, gold, titanium and surface-modified titanium screws, were tightened with 30 N-cm and unscrewed. As a result, they determined that the screw material most resistant to undoing was titanium (18.75 N-cm), gold (17.64 N-cm), and titanium (16.43 N-cm) with a modified surface, respectively. In our study, we preferred implant brands with titanium abutment screws.

Coppede et al. (157), in 2008, compared solid abutments in which the abutment and screw are one piece, and the systems in which the abutment and screw were two parts, in terms of undo-disassembly torque values. At the end of his in-vitro removal tests, he stated that there was a loss of 10.5% in solid abutments and up to 30% in two-piece abutments. We used two-piece implant abutment systems in our study.

In 2019, Ko et al. (135) compared the accuracy of tightening torque of three different electronic torque drivers. Three electronic torque drivers showed a significant difference in unscrewing torque values ($p < 0.001$). The tightening and unscrewing torques presented a moderate difference. The unscrewing torque values were considerably lower than the tightening torque values. The most precise unscrewing torques presented SAESHIN (33.1 ± 2.4 N-cm) at 35 N-cm, and NSK (15.1 ± 0.9 N-cm and 24.0 ± 1.4 N-cm) at 15 N-cm and 25 N-cm. Because the unscrewing torque might differ based on the tightening torques and electronic torque drivers, the electronic torque driver should be calibrated periodically. We used NSK electronic torque driver in our study. Although we checked, the low torque values might be due to calibration.

In 2019, Kim et al. (158) compared the tightening torque accuracy of three different electronic torque drivers applying two different measuring strategies: pure output torque (POT) and clinical output torque (COT). (158) For all approaches, evaluations were carried out at torque settings of 10, 20, 30, and 40 N-cm, ten times for each configuration, with each driver evaluated. (158) At a torque of 30 N-cm, POT was substantially greater than COT. Finally, they concluded that the clinician should consider the maximum torque generated by the electronic torque driver when tightening an implant screw at 30 N-cm.

Researchers have tried many instruments to measure torque values accurately and reliably when the literature is examined. Norton 1999 (159), Al Rafee 2002 (160), Tzenakis 2002 (161) and Nigro (162) made their own preload measuring instruments with strain gauges in 2010, but over time digital instruments with international standards of calibration that everyone could use were needed. With the advancement of technology, Weiss 2000 (163), Squier 2002 (164), Coppede 2008 (157) and Stuker (156) started to use the digital torque meter in 2008, which provided more reliable results. We used a digital torque meter in this direction, which could be calibrated by international standards.

In 2008, Vallee et al. stated that mechanical torque limiting devices using spring-style components were significantly more precise than those using friction-style components in reaching threshold torque values. (126) In our study, one friction-style and one spring-style mechanical torque device were used.

In 2006, according to the results of Byrne et al., the gold-plated screw produced the maximum preloads for all insertion torques and tightening episodes. (165) Additional research focused on the impact of the screw and abutment types for each tightening session and attachment torque. The gold-plated screw attached to the manufactured abutment had greater preloads for the initial tightening at 10, 20, and 35 N-cm. The identical screw secured to the cast-on abutment, on the other hand, revealed greater values for the second and third tightening for all fixation torques. All screws demonstrated preload erosion as the count of tightening increased.

In 2019, Petrich et al. compared the reverse torque values (RTVs) of abutment screws fastened from three angles. They demonstrated that all mean RTVs were less than the planned torque value of 35 N-cm, with ten per cent fewer specific values in each angulation group. (166) They found a significant difference between the mean RTVs: 31.16 ± 1.12 N-cm, 32.07 ± 0.97 N-cm, and 30.08 ± 0.88 N-cm, in the 0°, 10°, and 20° groups, respectively. Additionally, none of the RTVs could reach the targeted torque value of 35 N-cm. Finally, they concluded that screwdriver insertion angulation had a substantial impact on mean screw RTVs. The implants and abutments in our investigation were angleless and parallelly inserted.

In implant-supported prostheses, the load during the function is transferred to the implant through the prosthetic parts abutment and screw. These loads are given a biological response by the hard and soft tissue surrounding the implant body.

In a study by Sutter et al., it was stated that the conical angled design created friction lock, which reduced screw loosening. (167) Compared to systems with external hexagonal connections, screwless threaded abutment systems reduce rotation to zero. According to previous studies, threaded abutment systems have approximately four times more compression properties than screw-connected systems. In addition, the loosening moment in threaded connections was 10-20% higher than the tightening torque, while in screwed connections, it was 10% less than the compression torque.

In the study of Jemt et al., it was observed that the connection screw met all static and dynamic lateral forces in external hexagonal connection systems, and the tensions were distributed on the screw surface. (168) They stated that the bending forces due to the function, which occur with the effect of lateral forces, usually led to the loosening of the screw or fracture due to fatigue.

Gehrke et al. investigated the effect of different tightening torque values on the linear gap in the implant-abutment contact in morse-conical implants and abutments. They measured the distance. As a result of the study, it was reported that as the torque value applied to the abutment screw increased, the linear area between the abutment and implant contact increased, and the gap decreased, and 35 N-cm was the most appropriate value for this connection type. It was emphasized that the morse-conical connection type provided better abutment compatibility, stability and sealing due to its mechanical properties (169). According to the result of our study, although the higher torque of the ratchet was seen as an advantage in this regard, it was known that too much torque could cause screw breakage.

Implants in the mouth are in contact not only with the bone but also with the gingiva. Although rigid acrylic models representing the bone were used in our study, no material representing the gingiva was used. Future studies in which the gingiva is also simulated in modelling may yield different results.

In our study, we focused on the unscrewing values of abutments and prosthetic screws in screw-retained implant-supported fixed prostheses. In cement-retained prostheses, unlike screw-retained ones, the abutments are attached to the implant with a separate screw, there is no separate screw for the prosthesis, and the prosthesis is placed on the abutments with cementation. There is a need for further studies on issues such as the unscrewing values of the abutment screw and the effect of cement in cement-retained implant-supported fixed prostheses.

CONCLUSION

1) When the unscrewing values obtained from the implants' own rachets were evaluated in all three unscrewing values, the unscrewing value obtained from Alpha Dent implants was found to be higher than that of Mode implants. This difference was found to be 35.7% at 15 N-cm, 4.7% at 25 N-cm, and 5.1% at 35 N-cm. Among these results, the difference in the 15 N-cm unscrewing value was statistically significant ($p<0.05$).

2) When the unscrewing values obtained from the automatic screwdrivers were evaluated in all three unscrewing values, the unscrewing value obtained from Alpha Dent implants was found to be higher than that of Mode implants. This difference was 12.9% for 15 N-cm, 9.8% for 25 N-cm, and 2.8% for 35 N-cm.

3) The unscrewing values obtained from the Alpha Dent brand's own ratchet were found to be higher than the unscrewing values obtained from the automatic screwdriver in all three unscrewing torque values. This difference was 19.3% at 15 N-cm, 2.5% at 25 N-cm, and 4.5% at 35 N-cm. The difference in the 15 N-cm unscrewing torque value was statistically significant ($p<0.05$).

4) The unscrewing value obtained from the Mode implant brand's own ratchet was found to be higher than the unscrewing value obtained from the automatic screwdriver at 25 N-cm and 35 N-cm unscrewing values. On the other hand, the unscrewing value obtained from the automatic screwdriver at 15 N-cm torque value was found to be higher than the unscrewing value obtained from its own ratchet. This difference was 0.8% for 15 N-cm, 7.4% for 25 N-cm, and 2.2% for 35 N-cm.

5) When all the unscrewing values were examined collectively, the unscrewing values obtained from the implant brands' own ratchets were found to be higher than the unscrewing values obtained from the automatic screwdrivers in all three unscrewing torque values. This difference was 9.2% for 15 N-cm, 4.4% for 25 N-cm, and 3.3% for 35 N-cm. The difference in the 15 N-cm removal value was significant ($p<0.05$).

Our study is a pioneering study as it is not similar to any previous study in the literature. More studies are needed on this subject to contribute the literature.

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